Optimization of Conical Antenna Array Synthesis using Modified Cuckoo Search Algorithm

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Optimization of Conical Antenna Array Synthesis using Modified Cuckoo Search Algorithm

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C E R T I F I C A T E

This is to certify that the thesis entitled ***"Optimization of Conical Antenna Array Synthesis using Modified Cuckoo Search Algorithm"*** *by* ***Mr. JOSHI KATTA****, submitted to the National Institute of Technology, Rourkela (Deemed University) for the award of Master of Technology in Electrical Engineering, is a record of bonafide research work carried out by him in the Department of Electrical Engineering , under my supervision. I believe that this thesis fulfills part of the requirements for the award of degree of Master of Technology.The results embodied in the thesis have not been submitted for the award of any other degree elsewhere.*

Prof.K. R. Subhashini

Place:Rourkela
Date:

To My Loving parents and Inspiring GUIDE

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Contents

Abstract

This thesis presents a modelling of conical antenna array (CAA) and synthesizing this array for a radiation pattern using modified cuckoo algorithm (MCS). Conventional arrays are also taken up as a preliminary study and optimisation of basic geometrics like linear and circular antenna arrays. The modelling carried out by tuning the antenna array parameters like amplitude excitation, complex amplitude excitation and angular distance. Analysis on the conventional and conformal geometries are carried out aiming for a desired pattern. Analysed simulation results gives the insight that, modelled conical array gives the pattern comprising of directivity, HPBW and SLL. Further commercial software package (CST) is used to design a working prototype model. The practical element chosen for the CST model is a dipole patch. The proposed technique is verified with the publishes literature results.

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List of Abbreviations

Abbreviation	Description
AF	Array Factor
MCS	Modified Cuckoo Search
LAA	Linear Antenna Array
CiAA	Circular Antenna Array
CAA	Conical Antenna Array
HPBW	Half Power Beam Width
SLL	Side Lobe Level
MLL	Main Lobe Level
GUI	Graphic User Interface
CST	Computer Simulation Technology
PSO	Particle Swarm Optimisation
ε_{reff}	Effective Dielectric Constant

Chapter 1

Introduction

1.1 Introduction

In so many applications it is desired that the radiated power to be concentrated in a certain direction is required. This can't be achieved by the single radiating element because single radiating element provides low directivity and wider beam width. [1, 2, 3, 4]. Antenna arrays can be adjusted in different geometries depending on the placement of each radiator on the coordinate system. The desired pencil beam pattern can be produced using the modelled conical antenna array (CAA)[5, 6]. In the process of obtaining the desired pencil beam pattern proper choice of controlling antenna parameters are required. Hence optimisation is adapted for the optimal set of controlling parameters [7, 8].

Deterministic methods does not meet the conceived requirement, hence new/modern methods can be experimented to reach the optimal set. Evolutionary technique is proposed to design the desired pencil beam pattern by the modified cuckoo search algorithm (MCS)[9, 10, 11, 12].

1.2 Literature Review

The single antenna element providing very less poor radiation pattern and it is not possible to concentrated in a certain direction that to it has low directivity and wider bandwidth and in some applications it is desired that the radiated power to be concentrated in a certain direction and it can be overcome by the antenna arrays and it provides more directivity, narrower HPBW [1, 2, 13, 3, 14]. The antenna arrays of basic geometrics like linear and circular are not reached the our desire pattern with the evolutionary technique modified cuckoo search algorithm (MCS) hence going to the conical antenna array design for the desired pattern and it is useful for the applications like submarine, satellite communications, point to point communications and more coverage [5, 8, 15].

Cuckoo search algorithm is an evolutionary technique newly developed and it is depend on the brood parasitism behaviour of cuckoo species. It has some disadvantages that convergence rate is less and also its search is entirely random hence for improving the search and some modifications done without changing the originality by the parameters step size, levi walk and P_a, these can be studied from the papers [16, 9, 10, 11, 12]. The pencil beam desired pattern by the basic geometrics linear and circular antenna arrays are not that much efficient that to they are not providing good directivity, HPBW and SLL [17, 18, 19], hence going to the conformal antenna of type conical giving good directivity, HPBW and SLL [20] for the modified cuckoo search algorithm for the array factor parameter optimisation of amplitude excitation, complex amplitude excitation and angular distance optimisation [21] with optimising the SLL and MLL and nullify the nulls [22, 7].

1.3 Objectives

- Design and synthesis of the conical antenna array (CAA).
- To change the parameters amplitude excitation, complex amplitude and angular distance in CAA for improving the performance.
- To achieve the desired pattern synthesis with modified cuckoo search (MCS) algorithm for CAA.
- To apply this desired pattern to the satellite communications, submarine

applications and steer the beam and more coverage possible with CAA.

- To achieve high directivity, HPBW and SLL for the required desired pattern.

1.4 Thesis Organisation

The thesis is organised as follows.

- Chapter 2, describes about the antenna arrays synthesis of conical antenna and basic geometries array antennas and its formulation and which parameters are optimising in the antenna arrays for getting the required desired pattern.

- Chapter 3, gives the overview of the evolutionary technique of modified cuckoo search algorithm and its improvement for producing of the required desired pattern.

- Chapter 4, shows the results of conical, linear and circular antenna array and showing that the conical antenna arrays producing the better results for the required desired pattern compared to the linear and circular antenna arrays.

- Chapter 5, designing and synthesis of the conical antenna array with patch dipole antenna as a element and producing the desired pattens and comparing these results with the simulation results.

- Chapter 6, concludes the thesis and extension of the future work.

Chapter 2

Modelling of Antenna Arrays

2.1 Antenna Arrays

In so many applications it is desired that the radiated power to be concentrated in a certain direction, with as little interference as possible with other directions and this can't be achieved by the single antenna element because it provides low directivity and wider beam width [1]. To increase the directivity and reducing the beam width, etc provide by increasing either electrical size of the antenna or assembly of radiating elements in a geometry configuration [13]. This multiple antenna is combination of the radiating elements hence referred as antenna array. The total array electrical field is determined by the vector addition of each individual element field radiated in a geometry [2, 14]. The symbol representation is $E_t = E_{sum\ of\ each\ individual\ element\ radiation\ pattern}$. There are five parameters to shape the overall pattern of the antenna. These are

1.Geometry configuration of the overall array

2.Relative pattern of individual antenna element

3.Amplitude excitation of individual antenna element

4.Relative displacement between the elements

5.Phase excitation of the individual elements

The parameters changed in the antenna arrays are amplitude excitation,complex amplitude excitation and angular distance between the elements for both basic geometries and conformal antenna (CAA).

2.2 Linear Antenna Array (LAA)

Consider a linear arrangement of M isotropic antenna elements are uniformly distributed with a spacing of distance 'd' in x-direction as discussed in figure 2.1. The array factor can be obtained by considering the elements to be point sources, the total field can be obtained by multiplying the array factor of the isotropic sources by the field of a single element.This is a pattern multiplication and it applies only for arrays of identical elements [2, 27, 4].i.e.

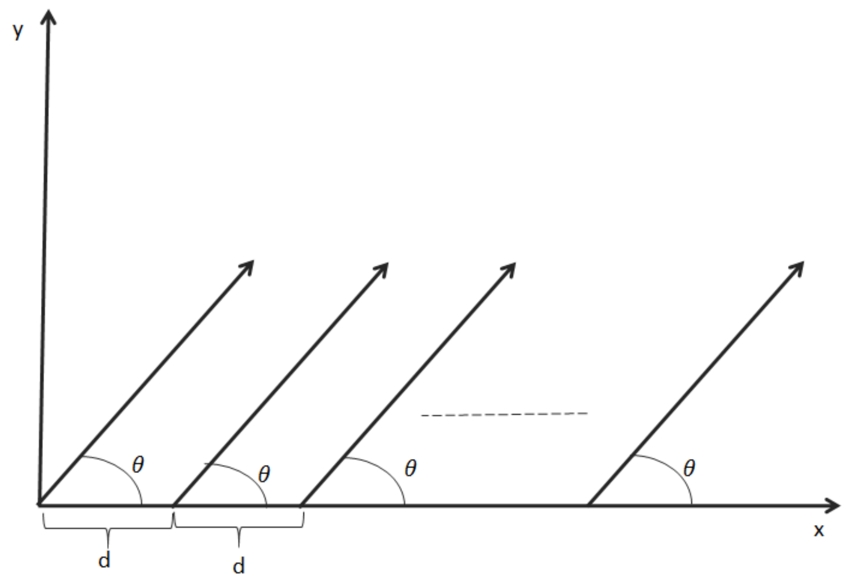

Figure 2.1: Geometric view of linear antenna array

$$E_{total} = [E_{singleelementatreferencepoint}] * [arrayfactor] \tag{2.1}$$

For M-element linear array antenna, the array factor is given by

$$(AF)_{linear} = \sum_{m=1}^{M} I_m e^{(j(m-1)(kdsin(\theta)cos(\phi)+\beta))} \tag{2.2}$$

where

P(r,θ,ϕ)=observation point

d=distance b/w two antenna elements

I_m=excitation coefficients
θ=elevation angle
β=progressive phase shift

2.3 Circular Antenna Array (CiAA)

Consider a circular arrangement of N isotropic antenna elements are uniformly distributed with an angular spacing of distance 'd' in $x - direction$ and the geometric view of a circular antenna array is shown by the figure 2.2.

For N element circular array with uniform angular spacing with a distance

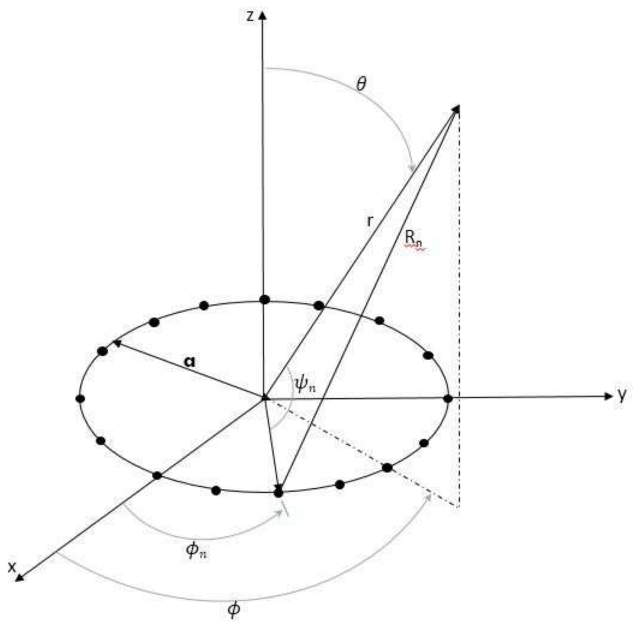

Figure 2.2: Geometric view of circular antenna array

$'d'$, the array factor is given by [2]

$$(AF)_{circular} = \sum_{n=1}^{N} I_n e^{(jka_n sin\theta cos(\phi-\phi_n)+\alpha_n)} \tag{2.3}$$

where

$\alpha_n = -jka_n sin\theta cos(\phi - \phi_n)$
P(r,θ,ϕ)=observation point
a_n=circle radius
d=angular spacing between the elements

I_n=excitation coefficients
ϕ_n=angular position of the n^{th} element in XY plane
α_n=phase excitation of the n^{th} element
β=progressive phase lead current relating to the preceding one

2.4 Conical Antenna Array (CAA)

Conical shaped antenna array represents the conformal antenna array (CAA) and particular interest for applications in the nose of streamlined airborne vehicles, rockets, and missiles. A pointed Conical shape offers wide-angle coverage, low radar cross section (RCS), good aerodynamic performance and submarine applications. Conical antenna array covers 180^0 coverage in azimuthal angle. The conical antenna array is 3-dimensional view and it can be synthesized by the linear combination of M circular stacks are arranged in z-direction [5, 28, 20]. The geometrical view of conical antenna array is shown by fig 2.3

where

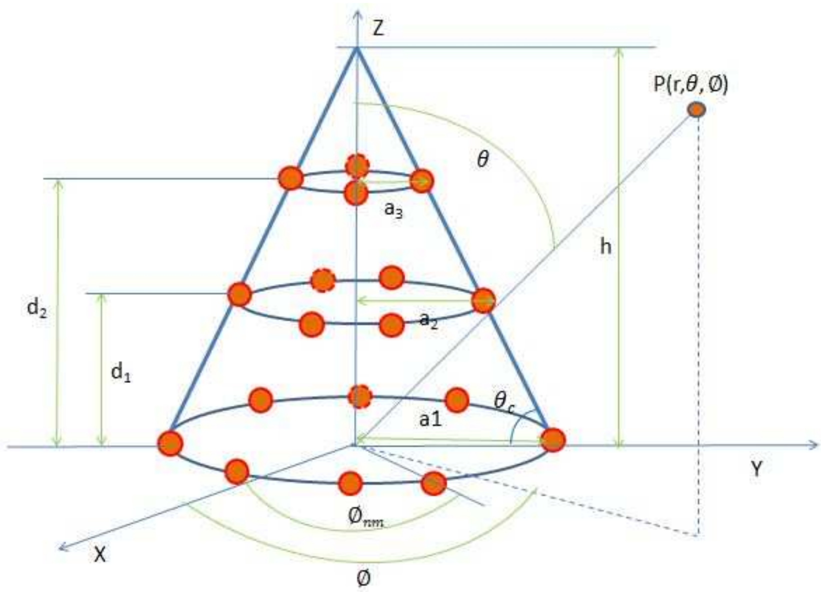

Figure 2.3: Geometric view of conical antenna array

P(r,θ,ϕ)=observation point
a_1=1st circle radius

a_2=2nd circle radius

a_3=top circle radius

d_1, d_2, d_3=distance b/w circles

θ_c=cone angle

k=wave number

λ=wave distance

N_0=Number of elements in the base circle

Mathematical Calculations:

From the Conical Antenna

the cone angle(θ_c) is same

$$tan\theta_c = \frac{(d \sim d_2)}{a_3} = \frac{(d \sim d_1)}{a_2} = \frac{h}{a_1} \tag{2.4}$$

$$d_1 = d_2 = d_3 = \frac{d}{3} \tag{2.5}$$

$$h = a_1 * tan\theta_c \tag{2.6}$$

From eq^n 2.4 and 2.5

$$a_2 = a_1 * \tfrac{2}{3}$$
$$a_3 = a_1 * \tfrac{1}{3}$$

For N number of elements

$$a_1 = \tfrac{N_0}{2*k}$$
$$\text{k} = \tfrac{2\pi}{\lambda}$$

2.4.1 Array factor formulation of conical antenna array

Conical antenna array can be designed by the linear arrangement of M-circular stacks in z-axis with an observation point P(r,θ,ϕ) in XZ plane. The array factor of the conical antenna array with N-linear arrangement of M-circular stacks is given by [20]

$$(AF)_{Conical} = \sum_{m=1}^{M} I_{nm} \sum_{n=1}^{N} e^{(jka_n sin\theta cos(\phi-\phi_n)+\alpha_n)} * e^{(j(m-1)(kdcos\theta+\beta))} \tag{2.7}$$

where

I_{nm}=Amplitude excitation coefficients

ϕ_{nm}=angular position of the m^{th} element of the n^{th} circle

α_n=phase excitation of the n^{th} element

β=relative phase of the reference element

α_n=phase excitation of the n^{th} element

β=progressive phase lead current relating to the preceding one

a_n=n^{th} circle radius = $a_1 * \frac{(N-1)}{N}$

By changing the antenna parameters like amplitude excitation, complex amplitude excitation, angular distance spacing and progressive phase lead current(β) in the design of conical antenna array we can provide required desired pattern and also we can achieve the high directivity, low HPBW and SLL.

where

HPBW = half power beam width

SLL = side lobe level

Conical antenna array viewed as a concentric circles

1.When $\theta = 90^0$ then visualization from the tip of cone the conical antenna is viewed as a concentric circles.

2.Beam Steering is possible and the coverage of conical antenna is 180^0

3.More Directivity can be achieved

The geometric view of a conical antenna array as a concentric circles is plotted in the figure 2.4

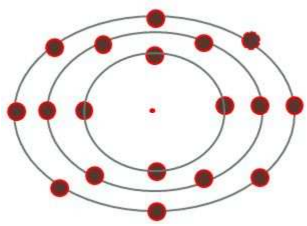

Figure 2.4: Geometric view of cone as a concentric circles

2.4.2 Parameters to be optimized

The parameters optimised in the conformal conical antenna array are uniform spacing and non-uniform spacing. These are divided into two types,

1.Uniform conical antenna array (UCA)

2.Non-uniform conical antenna array (NUCA)

Uniform conical antenna array (UCA)

In this case study, explaining about the uniform spacing in the conical antenna array and its graphical view of the uniform spacing is as follow in the figure 2.5 and uniform spacing is of two types:

1. Amplitude excitation uniform spacing
2. Complex amplitude excitation uniform spacing

In Amplitude Excitation and complex amplitude excitation the angular spacing between the elements is uniform i.e. $\theta_1 = \theta_2$ and shown in the figure 2.5.

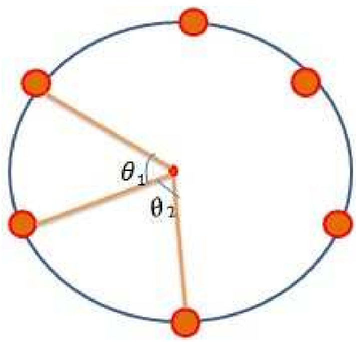

Figure 2.5: Uniform spacing conical antenna array

Amplitude excitation uniform spacing of CAA

In Amplitude Excitation the uniform spacing between the elements is constant and the angular distance between the elements in a circular stacks is given by $2\pi/N_m$ [5, 2, 21]. In amplitude excitation the variation of the current is given by the matrices

$$I = [I]_{NM} = [I_{11}, I_{12}...I_{1M} \quad I_{21}, I_{22}...I_{2M} \quad I_{N1}, I_{N2}....I_{NM}] \tag{2.8}$$

$I_{11}, I_{12}...I_{1M}$, $I_{21}, I_{22}...I_{2M}$ and $I_{N1}, I_{N2}...I_{NM}$ represents for the magnitude current excitation of the 1^{st}, 2^{nd} and M^{th}circular stack of conical antenna array.

The radiation pattern of a conical antenna array synthesis with amplitude excitation of uniform spacing from the eq^n 2.4 and shown in the figure 2.6. The radiation pattern plotted between the gain in dB and azimuthal angle(ϕ in degree) and the details of the radiation pattern with number of elements and distance b/w the elements, etc is explained in the below figure.

The details of the graph of radiation parameters are as follows.

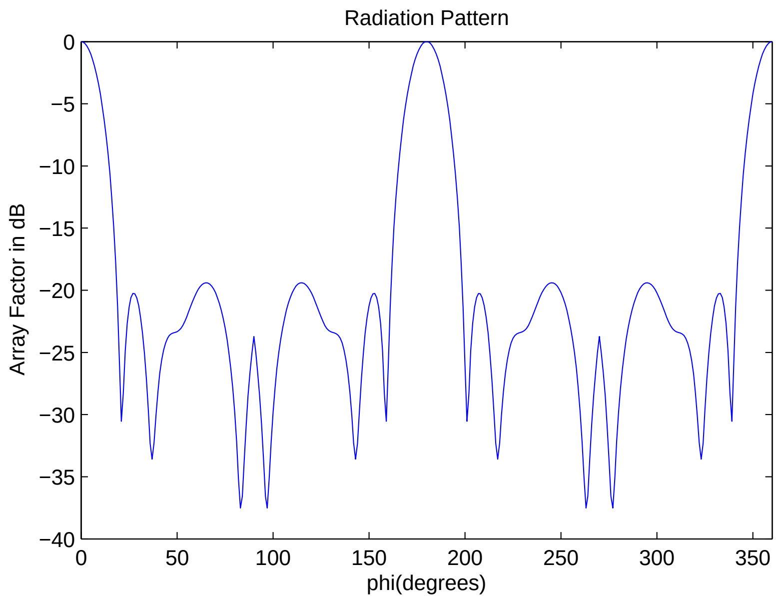

Figure 2.6: Ampliude excitation of UCA

No of circles=2

No of elements=36

Distance between two elements=$\frac{2\pi}{N}$

Mutual Coupling is neglected.

Calculation is only for far field.

Complex amplitude excitation of uniform spacing CAA

In complex amplitude excitation simultaneously change in both the magnitude and phase of the amplitude excitation, hence the variation is complex ,i.e. from eq^n 2.8

$$I = I_{real} + jI_{img} \tag{2.9}$$

I_{real}=Due to amplitude change

I_{img}=Due to phase of amplitude change

The radiation pattern of a conical antenna array synthesis with complex amplitude excitation of uniform spacing from the eq^n 2.4 and shown in the figure 2.7. The radiation pattern plotted between the gain in dB and azimuthal angle(ϕ in degree) and the details of the radiation pattern with number of elements and distance b/w the elements, etc is explained in the below figure.

The details of the graph of radiation parameters are as follows.

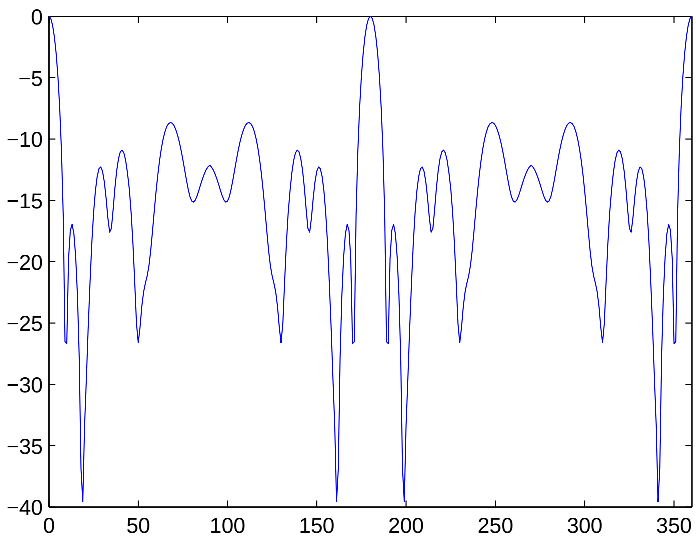

Figure 2.7: Complex ampliude excitation of UCA

No of circles=2

No of elements=36

Distance between two elements=$\frac{2\pi}{N}$
Mutual Coupling is neglected.
Calculation is only for far field.

Non-uniform conical antenna array (UCA)

In this case study, explaining about the non-uniform spacing in the conical antenna array and its graphical view of the non-uniform spacing is as follow in the figure 2.5 and is of the type: Angular distance non-uniform spacing CAA

In Angular Distance the angular spacing between the elements is non-uniform i.e. $\theta_1 \neq \theta_2$, i.e. explained by the figure 2.8 [5, 2, 21]

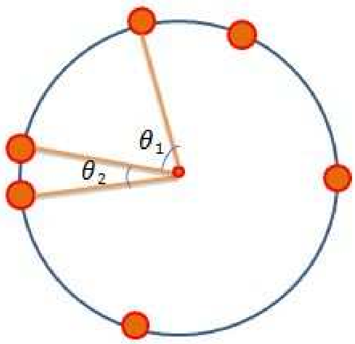

Figure 2.8: Non-niform spacing conical antenna array

Angular distance non-uniform spacing CAA

In Angular distance, the spacing between the antenna elements is non-uniform that can be observed from the figure 2.8 i.e. the variation is in the phase (azimuthal angle(ϕ)) is given by the matrices

Here phase is given by

$$\phi = [\phi]_{NM} = [\phi_{11}, \phi_{12}...\phi_{1M} \quad \phi_{21}, \phi_{22}...\phi_{2M} \quad \phi_{N1}\phi_{N2}....\phi_{NM}] \tag{2.10}$$

$\phi_{11}, \phi_{12}...\phi_{1M}$, $\phi_{21}, \phi_{22}...\phi_{2M}$ and $\phi_{N1}, \phi_{N2}....\phi_{NM}$ represents for the azimuthal angular spacing of 1^{st}, 2^{nd} and M^{th} circular stack of conical antenna array.

The radiation pattern of a conical antenna array synthesis with angular distance of non-uniform spacing from the eq^n 2.4 and shown in the figure 2.9.

The details of the graph of radiation parameters are as follows.

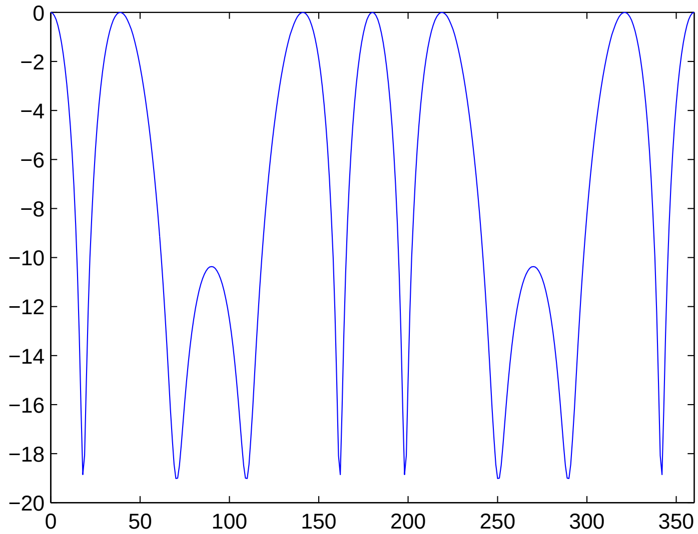

Figure 2.9: Non-uniform spacing conical antenna array

No of circles=2

No of elements=36

Mutual Coupling is neglected.

Calculation is only for far field.

Therefore for getting desired pattern, these parameters are optimized using modified cuckoo search algorithm for conical antenna array and this algorithm technique is applied to both linear array and circular antenna array also [1].

Chapter 3

Cuckoo search based synthesis of the CAA

3.1 Cuckoo Search Algorithm

Cuckoo search is a new meta heuristic search algorithm,based on cuckoo bird's behaviour and has been recently developed by Yang and Deb in 2009. Cuckoo search is a very new population heuristic algorithm for global optimization and it is one of the evolutionary technique, inspired by the reproduction strategy of cuckoos. At the most basic level, If a host bird discovers the eggs are not their own, it will either throw these alien eggs away or simply abandon its nest and build a new nest elsewhere. For simplicity in describing the cuckoo search, the 3 idealized assumptions are [9].

1. Each cuckoo lays one egg at a time, which represents a set of solutions dumps it in randomly chosen nest.

2.The best nests with high quality of eggs (solutions) will carry over to the next generations.

3.The number of available host nests is fixed, and a host can discover an alien egg with probability $P_a \epsilon$ [0,1]. In this case, the host bird can either throw the egg away or abandon the nest to build a completely new nest in a new location.

3.2 Modified Cuckoo search Algorithm

Given enough computation, the CS will always find the optimum solution for the required desired pattern but as the search entirely on random nature, a fast convergence cannot be guaranteed. This is the fail in the cuckoo search i.e can be overcome by the modified cuckoo search. Hence modified cuckoo search is made with the aim of increasing the convergence rate, thus making the method more practical for a wider range of applications but without losing the attractive features of the original CS method. An initial value of the Levy flight step size a = 0.1 is chosen and, at each generation, a new Levy flight step is calculated using α=A/$\sqrt{G}$, where G is the generation number. This exploratory search is only performed on the fraction of nests to be abandoned. For convenience the modified cuckoo search is named as cuckoo search through out the paper [11, 10].

When generating new solutions $x_i^{(t+1)}$ for the i^{th} cuckoo, the following Levy flight is performed.

$$x_i^{t+1} = x_i^t + \lambda \bigoplus Levy(\beta) \tag{3.1}$$

where λ is the step size which should be related to the scales of the problem of interests. In most cases, we can use $\lambda = 1$. The product $\bigoplus$ means entry-wise walk during multiplications [16]. Levy flights essentially provide a random walk while their random steps are drawn from a Levy Distribution for large steps

$$Levy \sim u = t^{(-1-\beta)}(0 < \beta < 2) \tag{3.2}$$

Here the consecutive jumps/steps of a cuckoo essentially form a random walk process which obeys a power-law step-length distribution with a heavy tail, this is provided by levy flight method. In addition, a fraction of the worst nests can be abandoned so that new nests can be built at new locations by random walks and mixing. The mixing of the eggs/solutions can be performed by random permutation according to the similarity/difference to the host eggs. Obviously, the generation of step size s samples is not trivial using Levy flights [12, 9]. A simple scheme discussed in detail by Yang can be summarized as

$$x_i^{t+1} = x_i^t + \lambda \bigoplus Levy(\beta) \sim 0.01 \frac{u}{|v|^{\frac{1}{\beta}}} * (x_j^t - x_i^t) \tag{3.3}$$

where and are drawn from normal distributions. i.e.

$$u \sim N(0, \sigma_u^2), v \sim N(0, \sigma_v^2) \tag{3.4}$$

The process of the modified cuckoo search algorithm for the conical antenna array for providing the required desired pattern is explained in the following figure 3.1

3.3 Antenna Analogy of Modified Cuckoo Search

The random population of 'n' host nests represents the 'n' number of solutions to the antenna array synthesis for providing the desired pattern. Out of 'n' host nests the cuckoo lies one egg at a time randomly means each egg is the solution of the each antenna element in the antenna design and from that we are calculating the fitness value, i.e. how much it fits to the required desired pattern. Again giving the random solution to the each nest producing the fitness value, therefore we comparing the fitness values of current and previous solutions and whose fitness value is less is the best solution of the current time , simultaneously which nests producing the worst solution with a probability of P_a then abandon that nest and in place of that creating a new nest in that location or elsewhere [9], and this process is continuous for the 't' number of iterations and for the '1' best run and we get the best solution of the desired pattern with MCS using antenna array synthesis. This process is continuous for the 'm' best runs with a random population of 'p' and producing a best solutions of 'm' for 't' iterations with 'm' best runs. Out of all these 'm' best solutions again we can decide the best solution out of 'm' best solutions

CSA	**Analogy**
Aim=Optimal reproduction of nest	Aim=Optimize the objective function
Eggs	Antenna Excitations
Population (N)	Number of Solution (N)
Generation	Iteration
Random nest	Random solution
while$(F_i < F_j)$	**Current sol < Previous sol**
If true previous nest is updated	Previous is the sol
If false current nest is updated	Current is the sol
Worst nest found with P_a Probability	Replace the solution with the other random solution
Repeat this upto t < $iter_{MAX}$	Repeat this upto the best solution
Best objective nest after all iter	Best solution after all iterations

Table 3.1: CSA Analogy with Antenna Analogy

by calculating the fitness of these and that one best suited to our required desired pattern. The Analogy is explained using the table 3.1 and explaining the relativeness of the algorithm in terms of antenna.

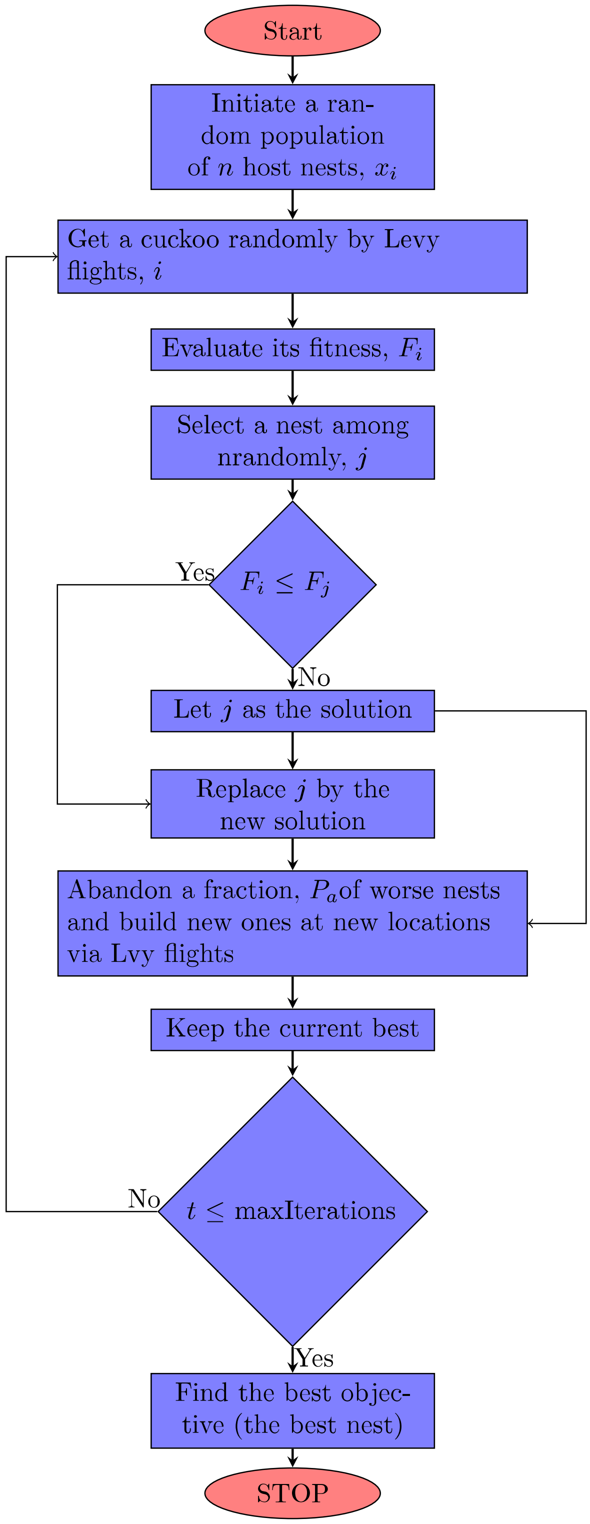

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Figure 3.1: Flow chart of a modified cuckoo search

Chapter 4

Simulation Analysis and Discussions

4.1 Desired pattern synthesis set up

• The desired pattern is pencil beam has a main beam width of 4^0 at [0^0,2^0], [178^0,182^0] and [358^0,360^0] and the remaining is the side lobe level(SLL).

• At high frequencies the noise will be added to the optimised pattern and it will be producing the more disturbed peaks in the SLL region hence for reducing these noise in the optimisation, introducing the ripple of 1 dB in the desired pattern, it will take care of optimising the noise at high frequencies level [17, 7, 1, 15, 19].

• The objective of the desired pattern synthesis is given by eq^n

$$f = \alpha * MLL + \beta * SLL \tag{4.1}$$

Considering

MLL represents main lobe level

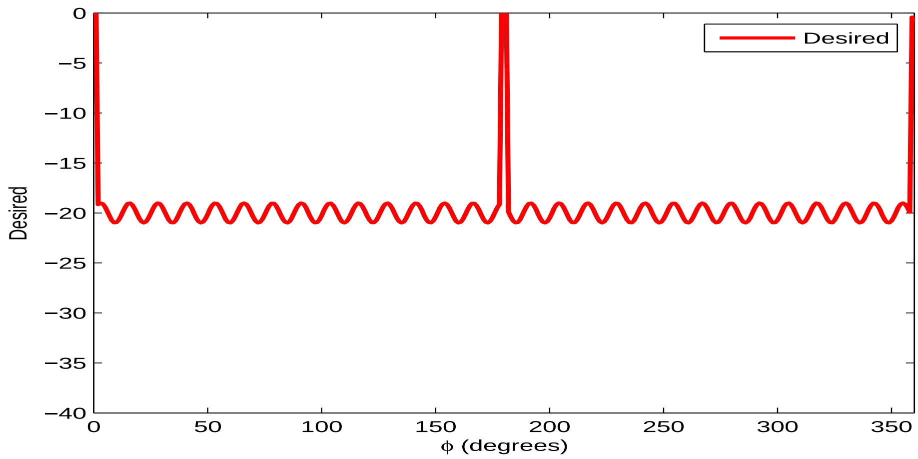
SLL represents side lobe level

f represents the fitness function

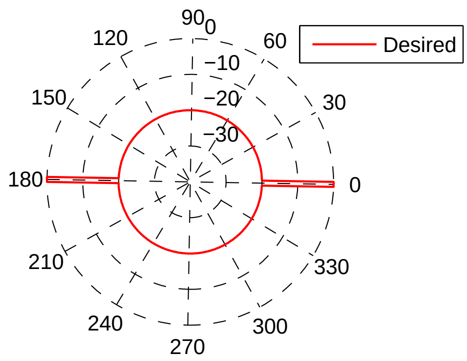
$\alpha = 0.8$

$\beta = 0.2$

The figure 4.1 shows the radiation pattern and polar plot of a pencil beam desired pattern [5, 13].



(a) radiation pattern



(b) polar plot

Figure 4.1: Radiation and polar plot of a desired pattern

4.2 Simulation set up

• The desired pattern,cuckoo search and uniform excitation are in red,blue and green colours respectively.

• The radiation pattern is a 2-dimensional plot , x-axis represents the azimuthal angle and y-axis represents the gain(dB).

• Similarly the polar plot represents the graph between the normalized array factor vs the ϕ(in degree) observed from the figure 4.1.

Considering

Parameter	Description
$P = 0.25$	Probability of alien eggs/solutions
$D = 55$	Population size
N=40	No. of nests
$iter = 1000$	Maximum Generation/iteration
$i = 10$	Best Runs
$MATLAB2012a$	Simulator

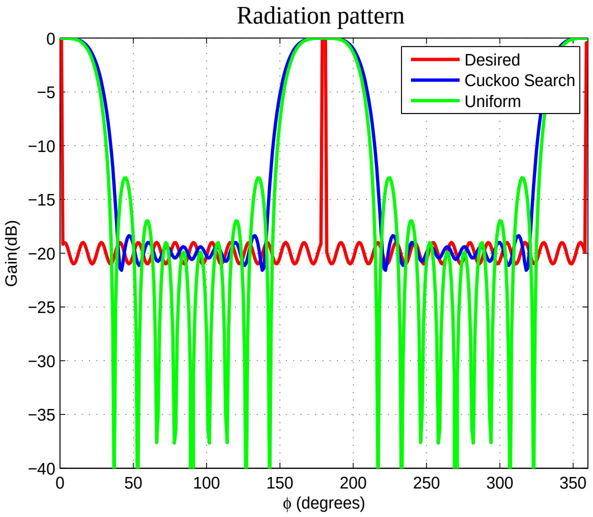
Table 4.1: Parameter setup

4.3 Case study 1: Linear Antenna Array

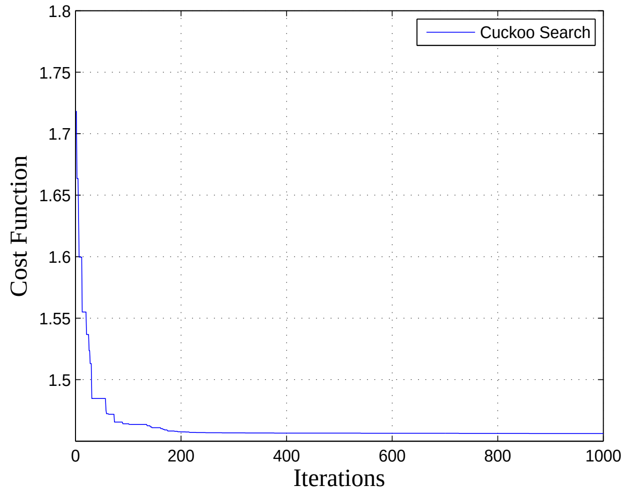
From the linear antenna array the parameters can be varied we can observed from the array factor eq^n 2.2, optimising the LAA for desired pattern synthesis with excitations of amplitude, complex amplitude and angular distance optimisations [6, 22].

4.3.1 Amplitude Excitation of LAA

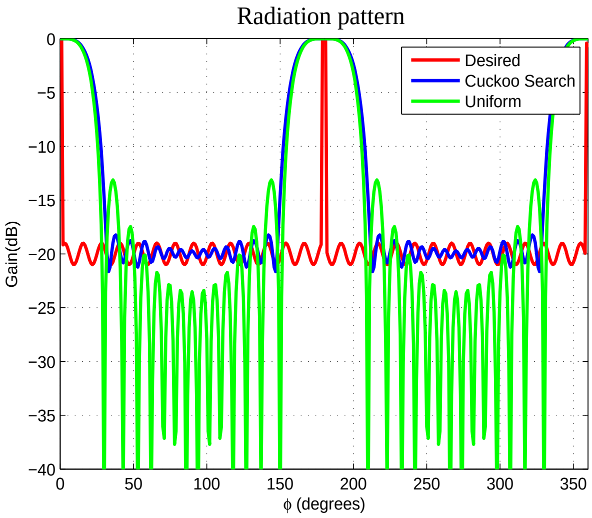
In amplitude excitation the amplitude(only magnitude) is varying and the below patterns are the radiation , cost function and polar plot for the linear antenna array with amplitude excitation with the number of elements are 10,15 and 20. As the number of elements are increasing the main beam becomes narrower and correspondingly the HPBW is also reducing and the side lobe level (SLL) is become lesser and from the amplitude excitation we are reaching the maximum directivity of 11.2 dB and HPBW of 34^0 with 20 elements and the side lobe level reaching a value of -18.37 dB with 10 number of elements we can observe from the figure 4.2 [29]. The cost function representing the how much the pattern is fitted in the desired pattern and it starts a value of 1.25 and ending with a value of 1.02 and these are for 1000 iterations with 10 best runs. The polar plot of the amplitude excitations of the linear antenna array is shown in the figure 4.3 [6, 22]. From the figure we are observing that as number of elements increasing it is reaching to the desired pattern we can clearly observe in the figure 4.3.



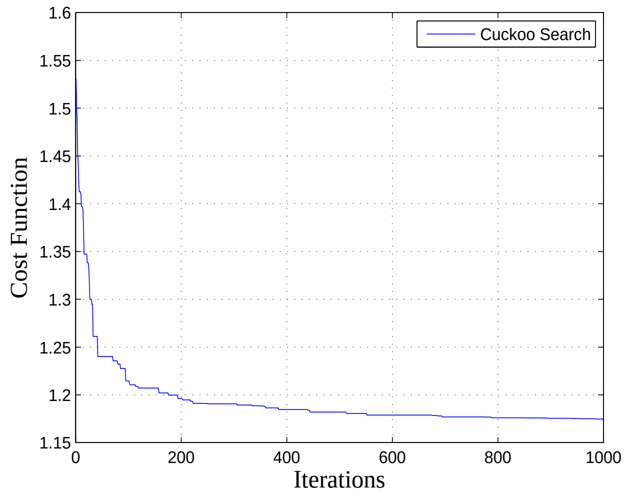
(a) Rad pat of 10 elements



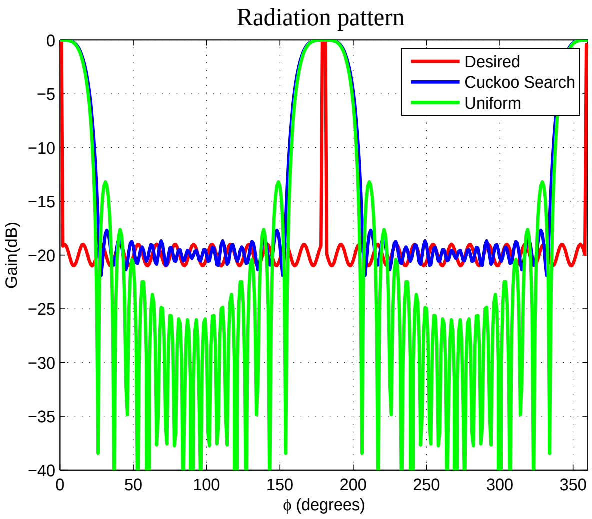
(b) cost fun of 10 elements



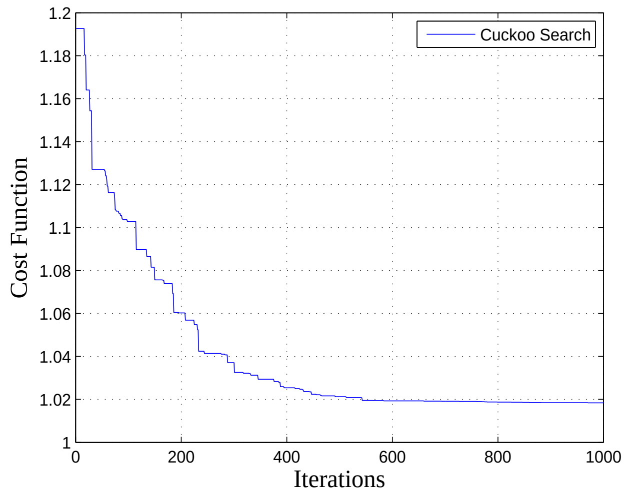
(c) Rad pat of 15 elements



(d) cost fun of 15 elements

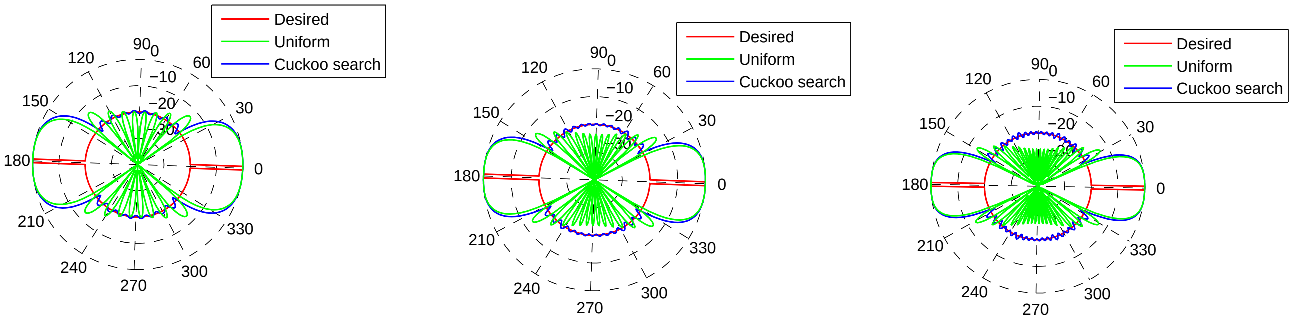


(e) Rad pat of 20 elements



(f) cost fun of 20 elements

Figure 4.2: Rad and cost fun of a LAA for amp excit

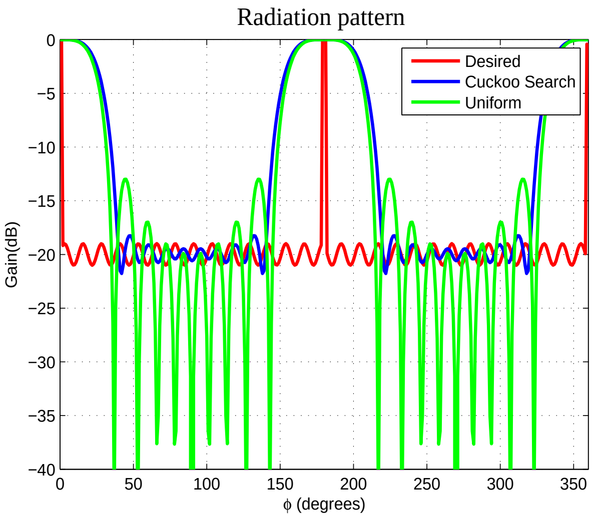


(a) n=10 elements (b) n=15 elements (c) n=20 elements

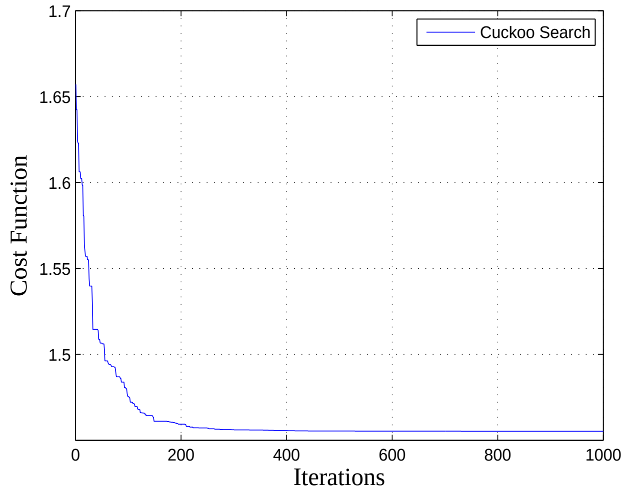
Figure 4.3: Polar plot of a LAA for amp excit

4.3.2 Complex Amplitude Excitation of LAA

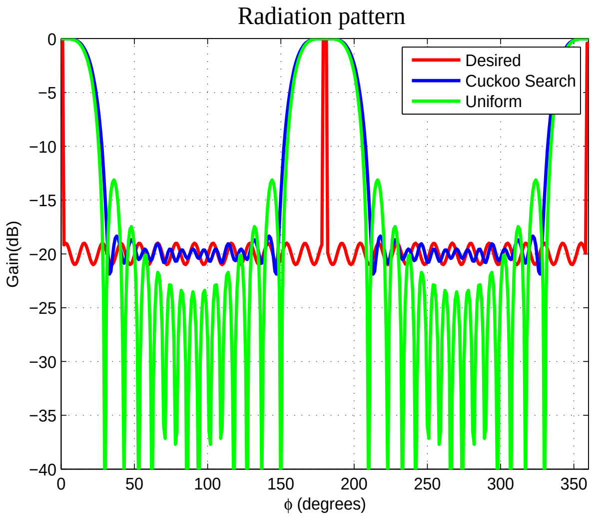
In complex amplitude excitation the magnitude and phase of a amplitude is varying simultaneously and the below patterns are the radiation , cost function and polar plot for the linear antenna array with complex amplitude excitation with the number of elements are 10,15 and 20. As the number of elements are increasing the main beam becomes narrower and correspondingly the HPBW is also reducing and the side lobe level (SLL) is become lesser compared to the amplitude excitation, and in complex amplitude excitation directivity reaching a maximum value of 11.8 dB and HPBW of ^{32} with 20 elements and the side lobe level reaching a minimum value of -18.85 dB with 20 number of elements and it can be observed from the figure 4.4 and cost function starts a value of 1.33 and ending with a value of 1.02 for 20 elements, and these are for 1000 iterations with 10 best runs and the values can be observed from the figure 4.4 [8]. The polar plot of the complex amplitude excitations of linear antenna array for number of elements 10,15 and 20 is observed from the figure 4.5 and for 20 elements it is reaching to the desired pattern compared to the 10 and 15 elements. By observing figures,the directivity, HPBW and SLL of complex amplitude excitation providing better performance compared to the amplitude excitations.



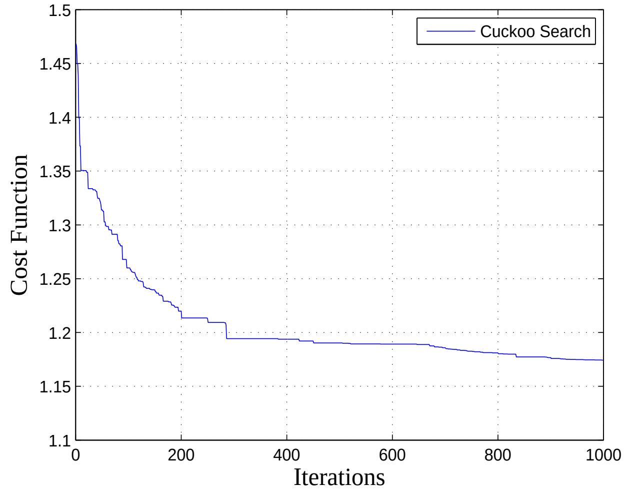
(a) Rad pat of 10 elements



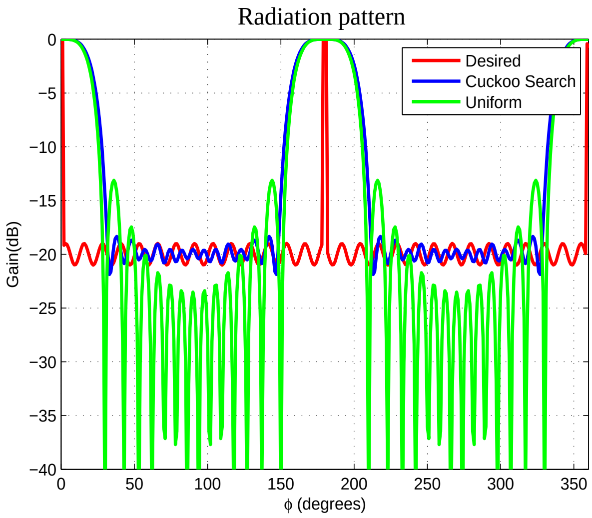
(b) cost fun of 10 elements



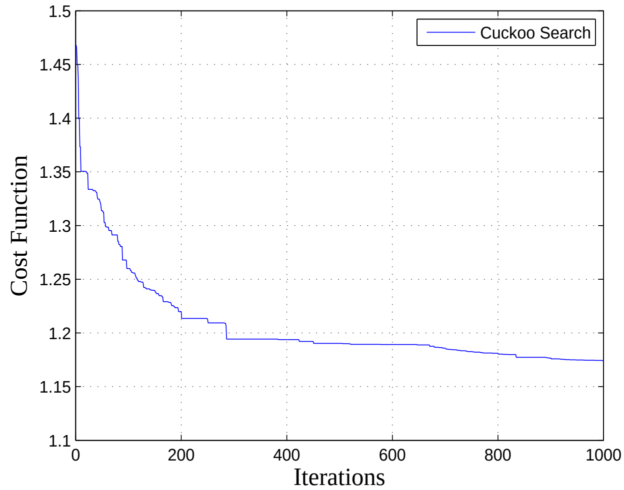
(c) Rad pat of 15 elements



(d) cost fun of 15 elements

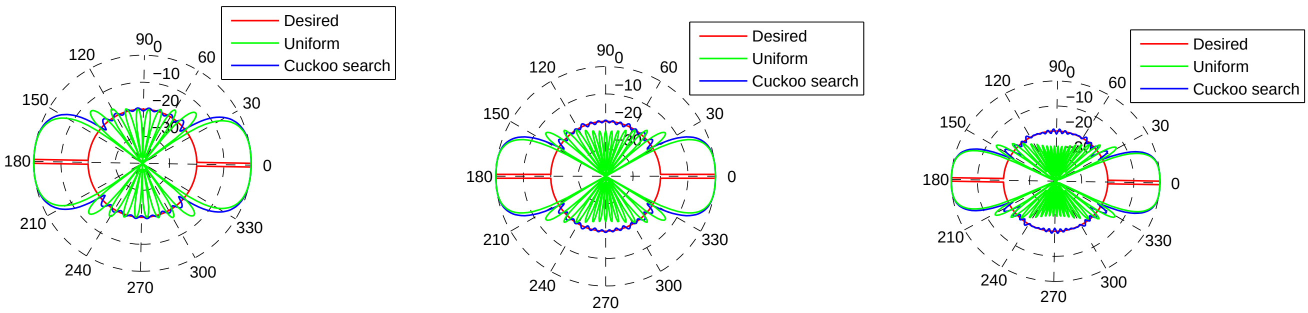


(e) Rad pat of 20 elements



(f) cost fun of 20 elements

Figure 4.4: Rad and cost fun of a LAA compx amp excit

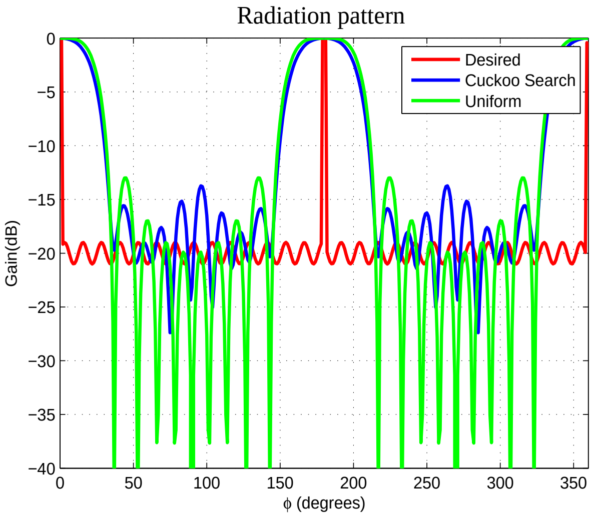


(a) n=10 elements (b) n=15 elements (c) n=20 elements

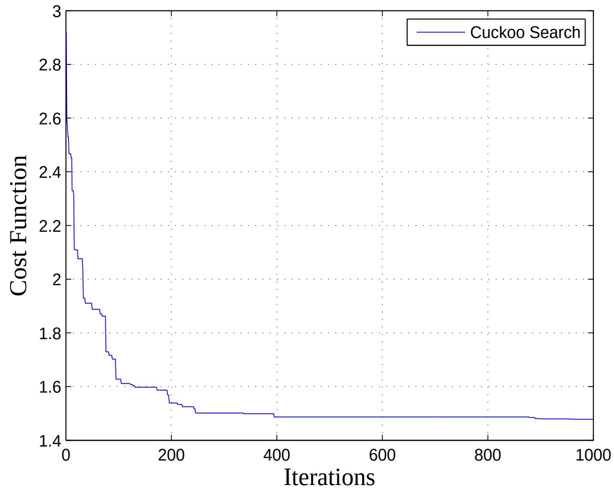
Figure 4.5: Polar plot of a LAA for compx excit

4.3.3 Relative distance optimisation of LAA

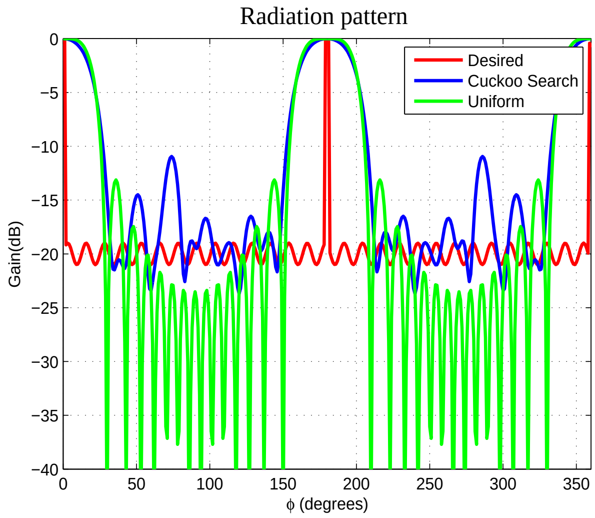
In relative distance optimisation, the distance b/w the elements is varying (means the spacing between the antenna elements are non-uniform) and the below patterns are the radiation , cost function and polar plot for the linear antenna array with angular distance optimisation with the number of elements are 10,15 and 20. As the number of elements are increasing the main beam becomes narrower and correspondingly the HPBW is also reducing and the side lobe level (SLL) is become lesser compared to the amplitude excitation and complex amplitude excitation and it's directivity reaching a maximum value of 12.11 dB and HPBW of ^{31} with 20 elements and the side lobe level reaching a minimum value of -17.26 dB with 20 number of elements and it can be observed from the figure 4.6 and cost function starts a value of 2.0 and ending with a value of 1.42 for 20 elements, and these are for 1000 iterations with 10 best runs and the values can be observed from the figure 4.6. The polar plot of the relative distance optimisation of linear antenna array for number of elements 10,15 and 20 is observed from the figure 4.7 and for 20 elements and it's providing better directivity and HPBW compared to complex amplitude and amplitude excitations and SLL produced by the relative distance is less compared to the complex amplitude and amplitude excitations [5, 23, 21].



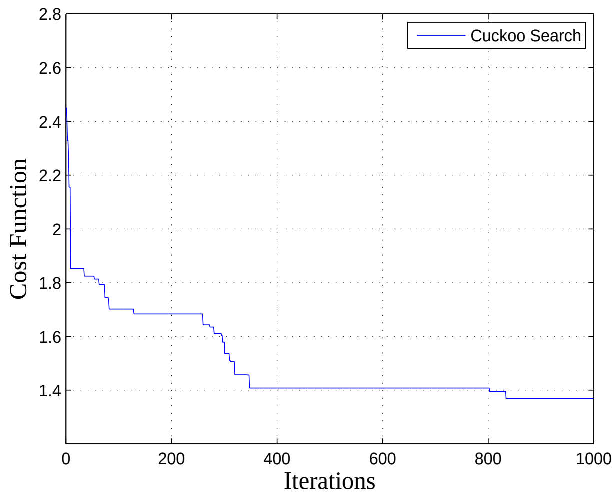
(a) rad pat of 10 elements



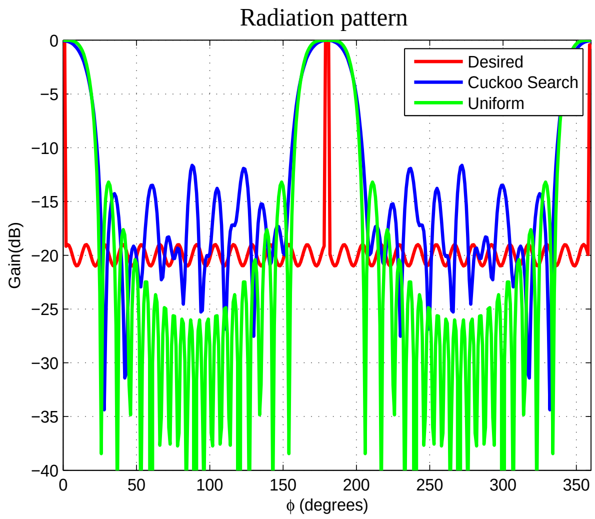
(b) cost fun of 10 elements



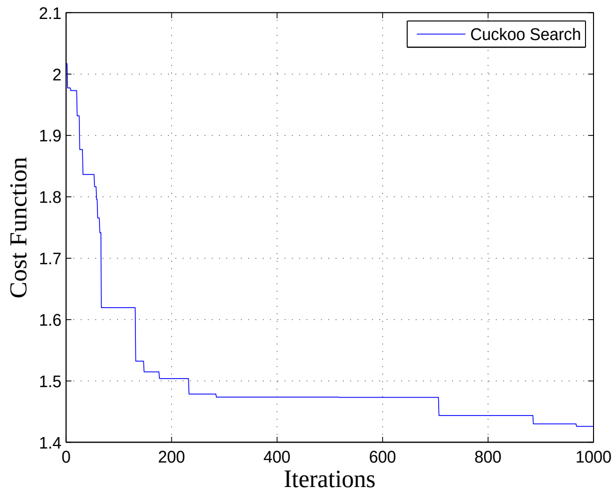
(c) rad pat of 15 elements



(d) cost fun of 15 elements

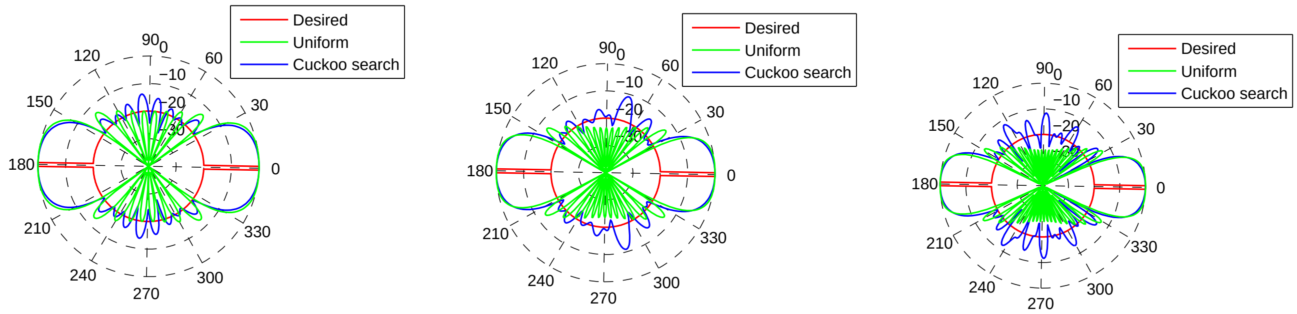


(e) rad pat of 20 elements



(f) cost fun of 20 elements

Figure 4.6: Rad and cost fun of a LAA for Ang dist



(a) n=10 elements (b) n=15 elements (c) n=20 elements

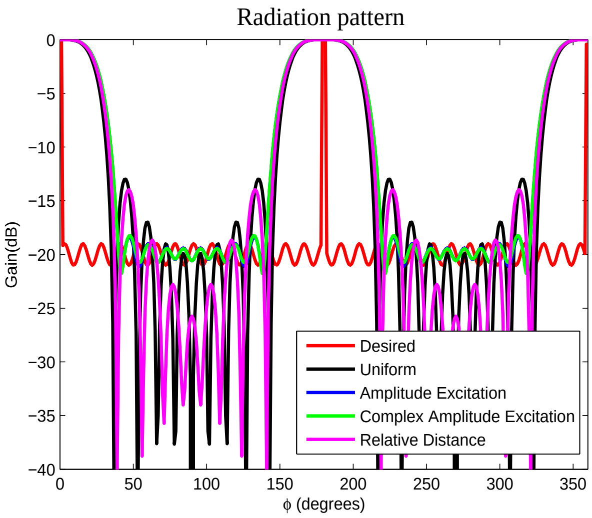
Figure 4.7: Polar plot of a lin ant array for Ang dist

4.3.4 Comparative and Statistical Results of LAA

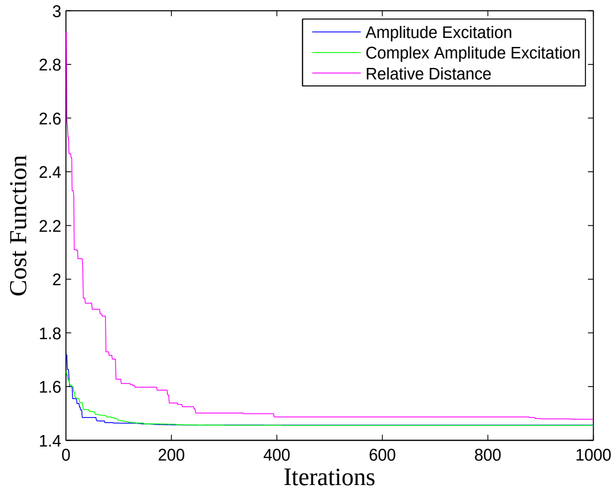
The statistical results of a linear antenna array with different excitations of amplitude, complex amplitude excitation and relative distance for the number of elements 10,15 and 20 using the MCS optimisation technique, calculated the the performance antenna parameters directivity, HPBW and SLL and it values observed in the table 4.2. From the table relative distance giving better directivity with a value of 12.5 dB, HPBW with a value of 28^0 for the 25 elements compared to the complex amplitude and amplitude excitation and complex amplitude excitation giving better SLL of -18.85 dB compared to amplitude excitation and relative distance optimisation 4.8.

No. of Elements	Directivity (dB)			HPBW (DEGREE)			SIDE LOBE LEVEL (dB)		
	Amp	C-Amp	Ang Dist	Amp	C-Amp	Ang Dist	Amp	C-Amp	Ang Dist
10	10	10.5	11.06	50	50	48	-18.37	-18.28	-15.2
15	10.5	11.0	11.58	40	38	38	-18.24	-18.35	-17.9
20	11.2	11.8	12.11	34	32	31	-18.02	-18.85	-17.26
25	11.7	12	12.5	30	29	28	-18.13	-18.31	-16.05

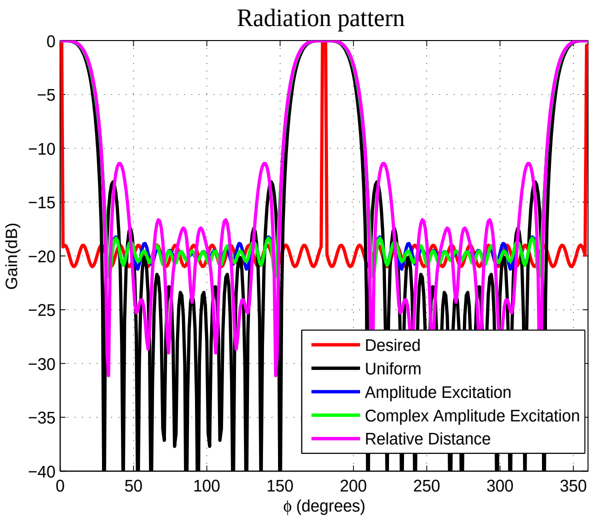
Table 4.2: Statistical results of a LAA



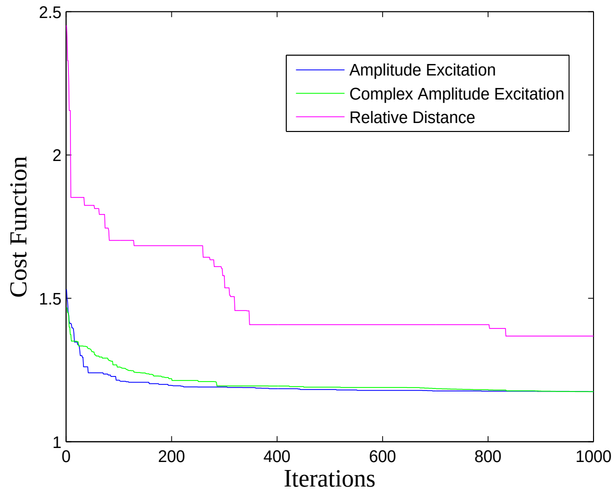
(a) rad pat of 10 elements



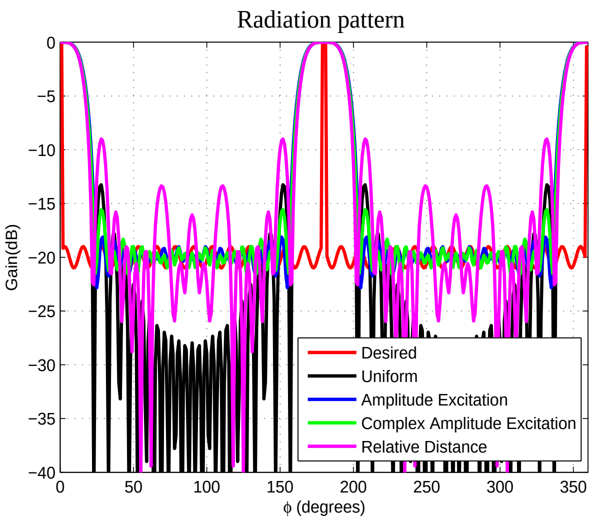
(b) cost fun of 10 elements



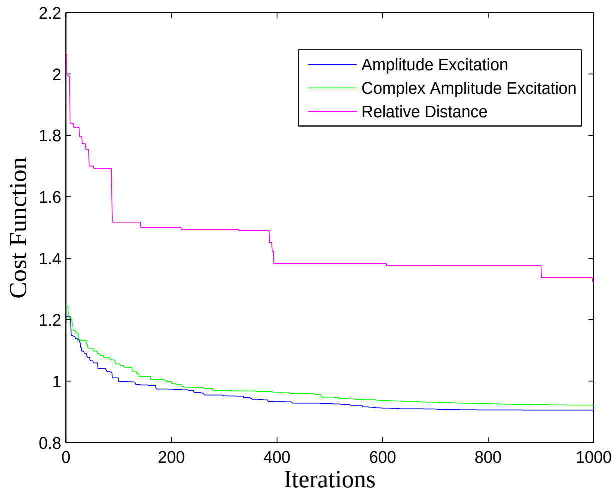
(c) rad pat of 15 elements



(d) cost fun of 15 elements



(e) rad pat of 25 elements



(f) cost fun of 25 elements

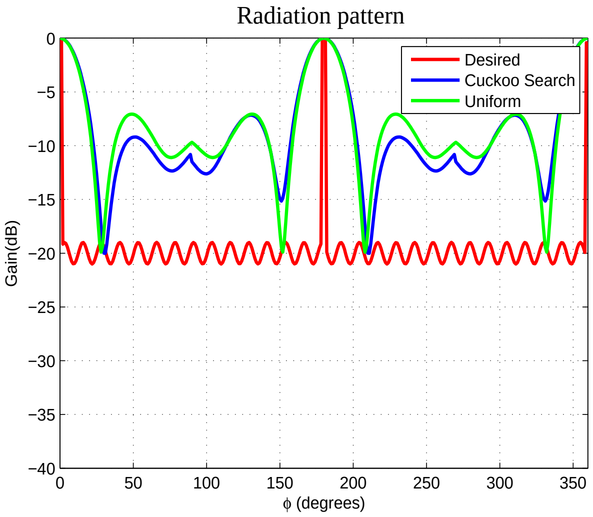
Figure 4.8: Combined plots of Rad and cost fun of a LAA

4.4 Case Study 2: Circular Antenna Array

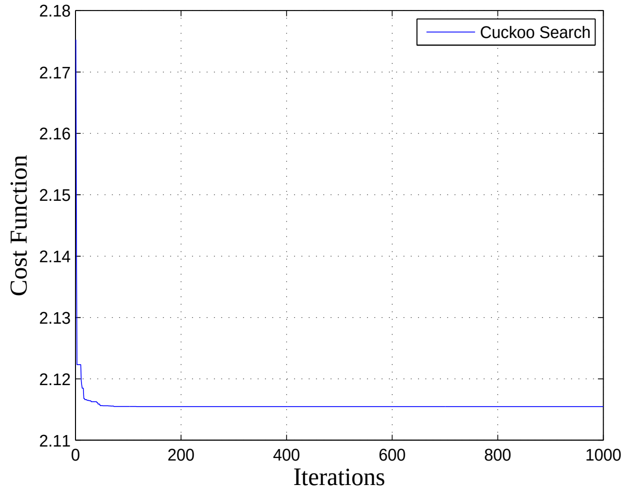
From the circular antenna array the parameters can be varied we can observed from the array factor eq^n 2.3, we can optimise the circular antenna array for desired pattern synthesis with excitations of amplitude, complex amplitude and angular distance optimisation using MCS algorithm [27, 17, 7].

4.4.1 Amplitude Excitation of CiAA

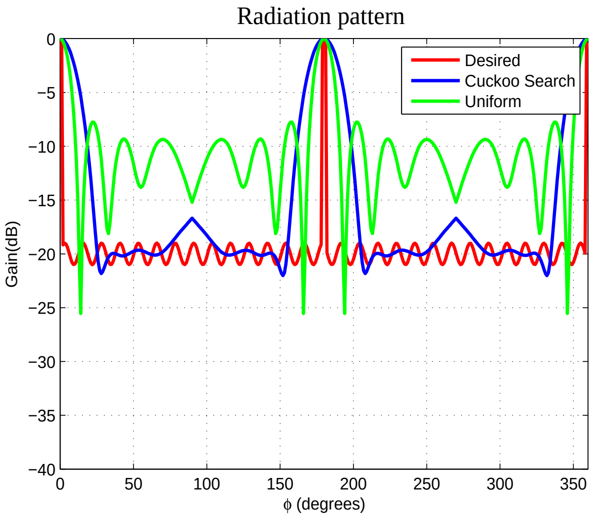
In amplitude excitation the amplitude(only magnitude) is varying and the below patterns are the radiation , cost function and polar plot for the circular antenna array with amplitude excitation with the number of elements are 10,20 and 30. As the number of elements are increasing the main beam becomes narrower and correspondingly the HPBW is also reducing and the side lobe level (SLL) is become lesser and from the amplitude excitation we are reaching the maximum directivity of 15 dB and HPBW of 16^0 with 30 elements and the side lobe level reaching a value of -17.92 dB with 30 number of elements we can observe from the figure 4.9 [18, 21]. The cost function representing the how much the pattern is fitted in the desired pattern and it starts with a value of 1.25 and ending with a value of 0.55 and these are for 1000 iterations with 10 best runs. The polar plot of the amplitude excitations of the circular antenna array is shown in the figure 4.10 for the number of elements 10,20 and 30. From the figure we are observing that as number of elements increasing it is reaching to the desired pattern we can clearly observe in the figure 4.10. The antenna parameters directivity, HPBW and SLL values observe from the table , n=30 elements providing more directivity and from the table 4.3, the circular antenna array providing better perfomance(desired pattern) compared to linear antenna array we can observe from the table 4.3 and 4.2.



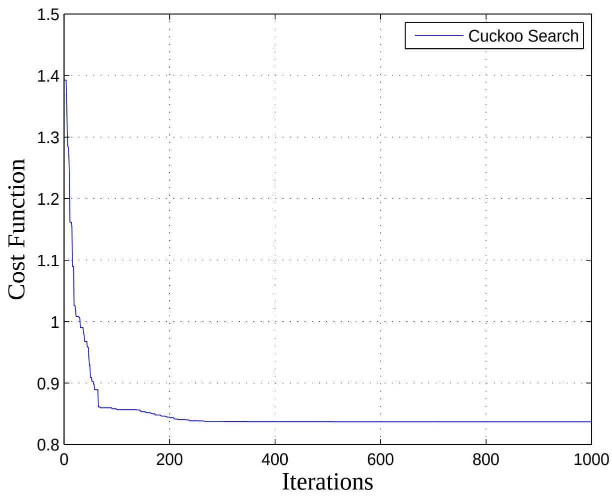
(a) rad pat of 10 elements



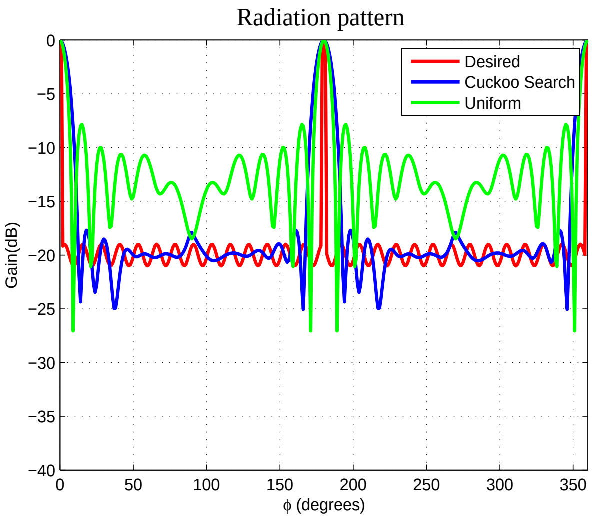
(b) cost fun of 10 elements



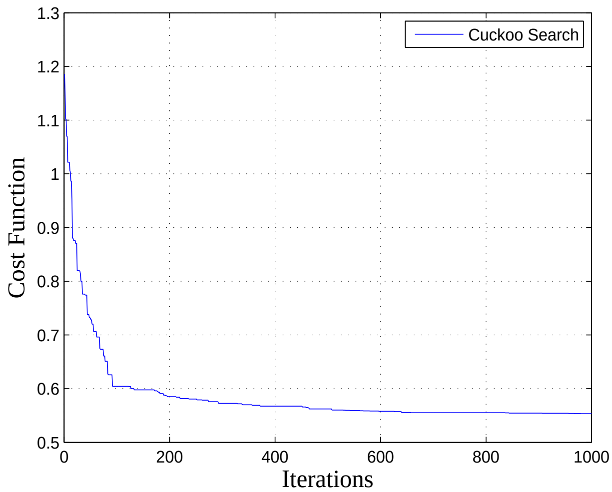
(c) rad pat of 20 elements



(d) cost fun of 20 elements

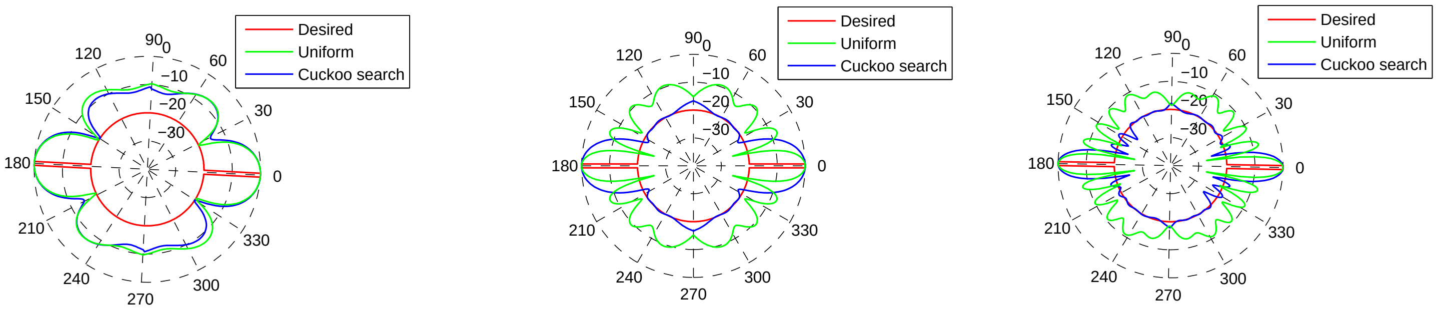


(e) rad pat of 30 elements



(f) cost fun of 30 elements

Figure 4.9: Rad and cost fun of a CiAA for amp excit

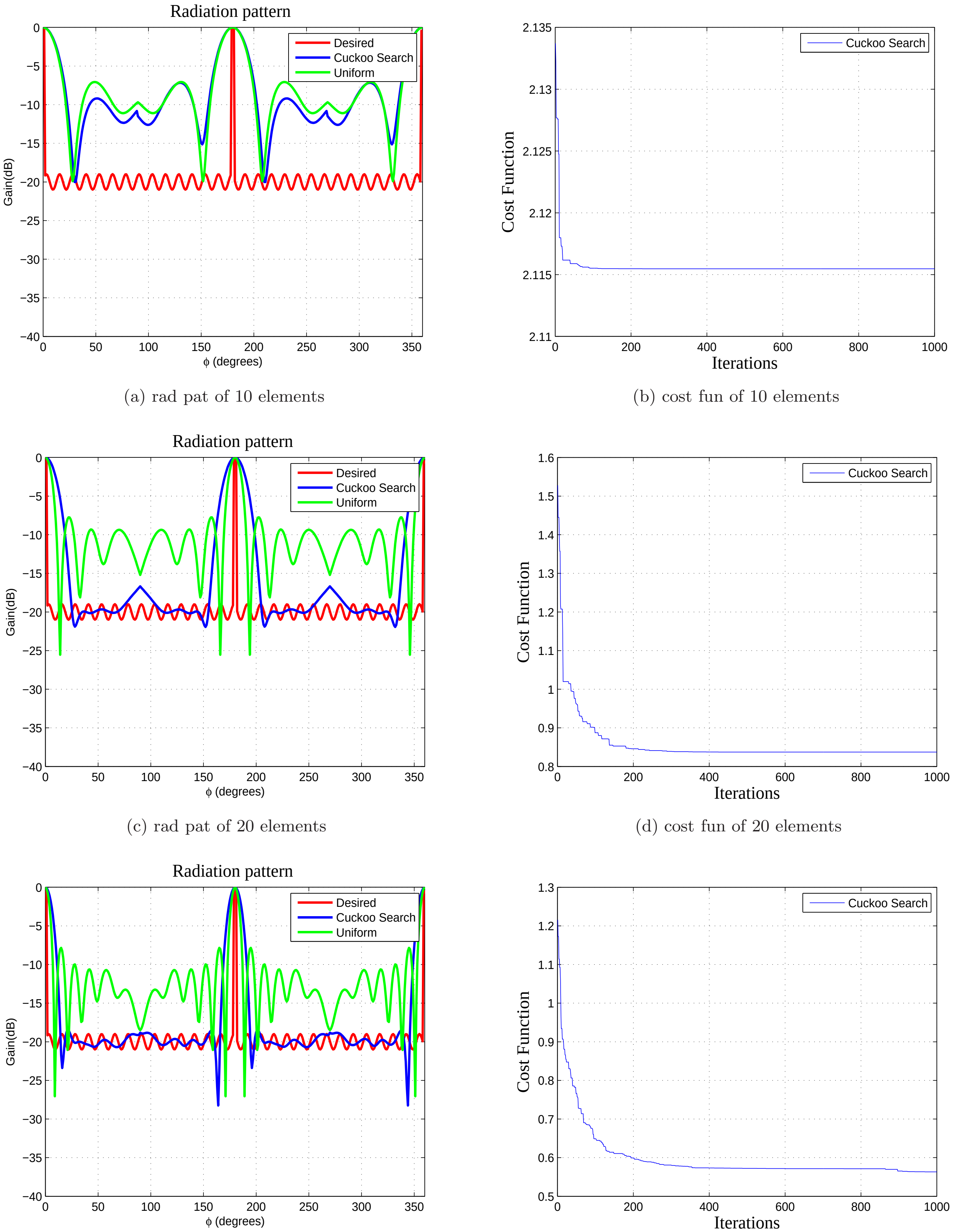


(a) n=10 elements (b) n=10 elements (c) n=10 elements

Figure 4.10: Polar plot of a CiAA for amp excit

4.4.2 Complex Amplitude Excitation of CiAA

In complex amplitude excitation the magnitude and phase of a amplitude is varying simultaneously and the below patterns are the radiation , cost function and polar plot for the circular antenna array with complex amplitude excitation with the number of elements are 10,20 and 30. As the number of elements are increasing the main beam becomes narrower and correspondingly the HPBW is also reducing and the side lobe level (SLL) is become lesser compared to the amplitude excitation, and in complex amplitude excitation directivity reaching a maximum value of 15.51 dB and HPBW of 14^0 with 30 elements and the side lobe level reaching a minimum value of -19.5 dB with 20 number of elements and it can be observed from the figure 4.11 and cost function starts with a value of 1.3 and ending with a value of 0.58 for 30 elements, and these are for 1000 iterations with 10 best runs and the values can be observed from the figure 4.4. The polar plot of the complex amplitude excitations of circular antenna array for number of elements 10,20 and 30 is observed from the figure 4.12 and for 30 elements it is reaching to the desired pattern compared to the 10 and 20 elements. By observing figures,the directivity, HPBW and SLL of complex amplitude excitation providing better performance compared to the amplitude excitations [6, 18, 29]. The statistical values are showed in the table 4.3.



(a) rad pat of 10 elements

(b) cost fun of 10 elements

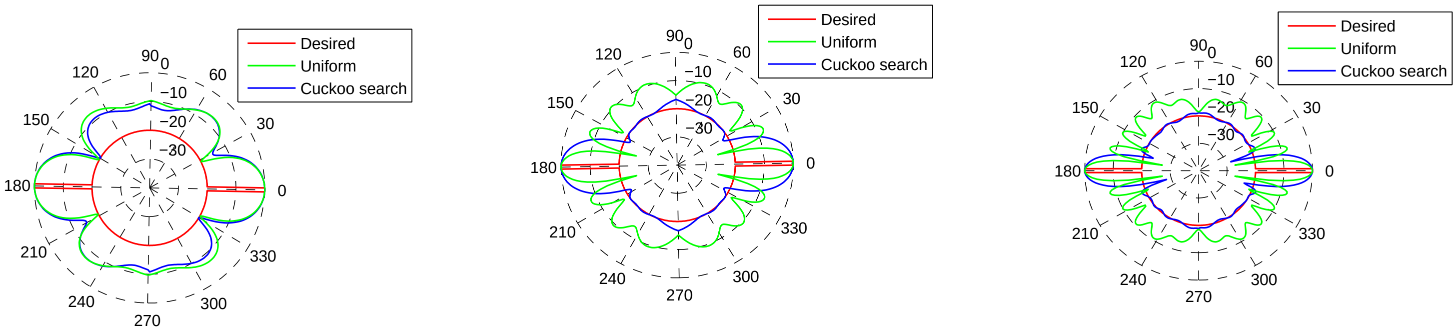
(c) rad pat of 20 elements

(d) cost fun of 20 elements

(e) rad pat of 30 elements

(f) cost fun of 30 elements

Figure 4.11: Rad and cost fun of a CiAA for compx amp excit

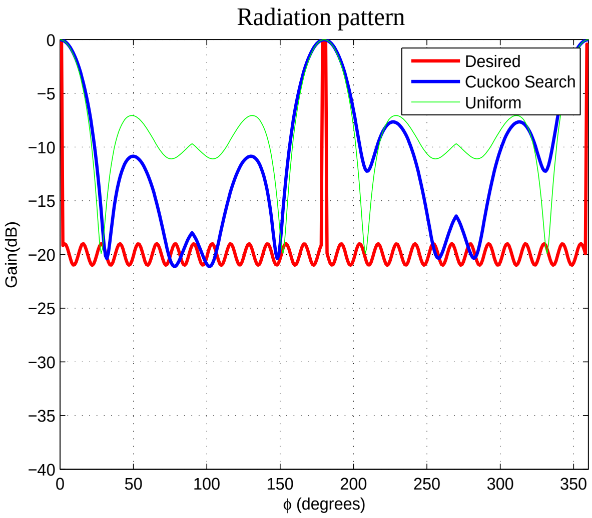


(a) n=10 elements (b) n=20 elements (c) n=30 elements

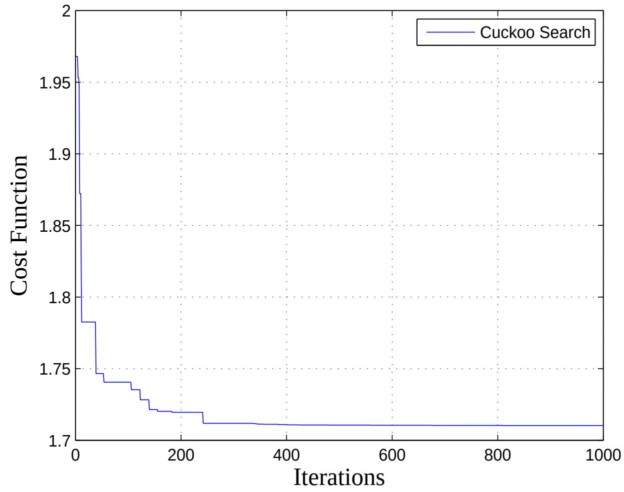
Figure 4.12: Polar plot of a CiAA for compx amp excit

4.4.3 Angular Distance Optimisation of CiAA

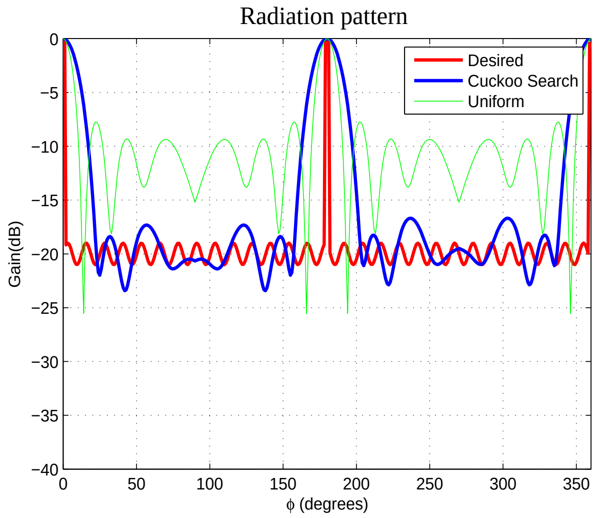
In angular distance optimisation, the azimuthal angle (ϕ) is varying and the patterns with the number of elements are 10,20 and 30. As the number of elements are increasing the main beam becomes narrower and correspondingly the HPBW is also reducing and the side lobe level (SLL) is become lesser compared to the amplitude excitation and complex amplitude excitation and it's directivity reaching a maximum value of 15.85 dB and HPBW of 12^0 with 30 elements and the side lobe level reaching a minimum value of -18.39 dB with 20 number of elements and it can be observed from the figure 4.13 and cost function starts with a value of 1.4 and ending with a value of 0.75 for 30 elements, and these are for 1000 iterations with 10 best runs and the values can be observed from the figure 4.13. The polar plot of the angular distance optimisation of circular antenna array for number of elements 10,20 and 30 is observed from the figure 4.14 [11, 9] and for 30 elements it is providing better directivity and HPBW compared to complex amplitude and amplitude excitations and SLL produced by the angular distance is less compared to the complex amplitude and amplitude excitations. The circular antenna array providing better desired patten compared to the linear antenna array and its statistical results can be observed from the table 4.3 and 4.2.



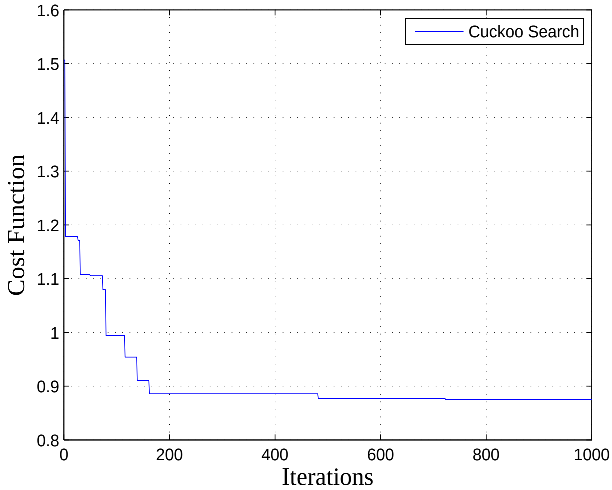
(a) rad pat of 10 elements



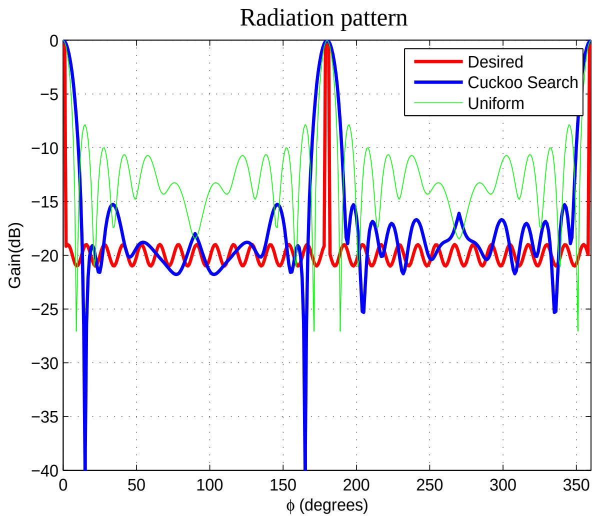
(b) cost fun of 10 elements



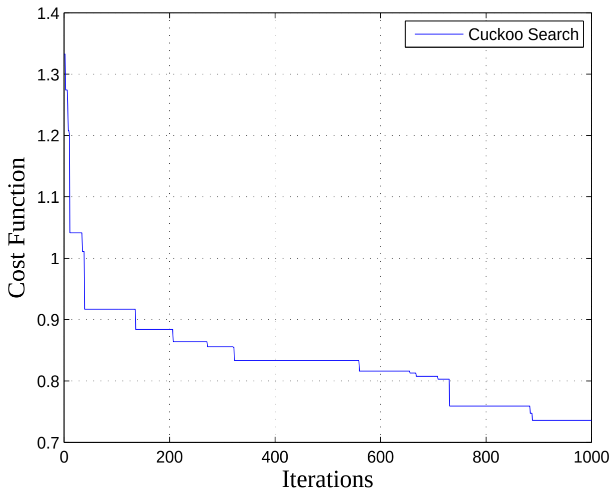
(c) rad pat of 20 elements



(d) cost fun of 20 elements

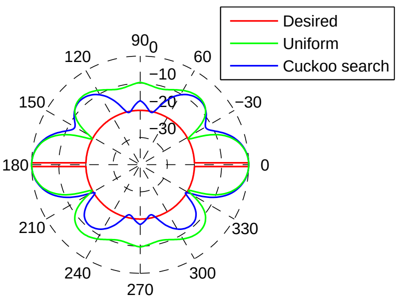


(e) rad pat of 30 elements

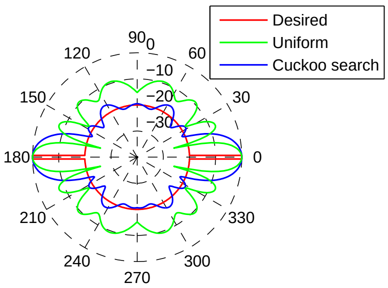


(f) cost fun of 30 elements

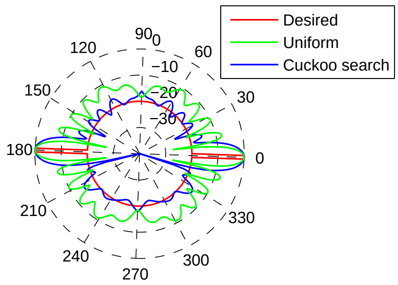
Figure 4.13: Rad and cost fun of a CiAA for ang diste



(a) n=10 elements



(b) n=20 elements



(c) n=30 elements

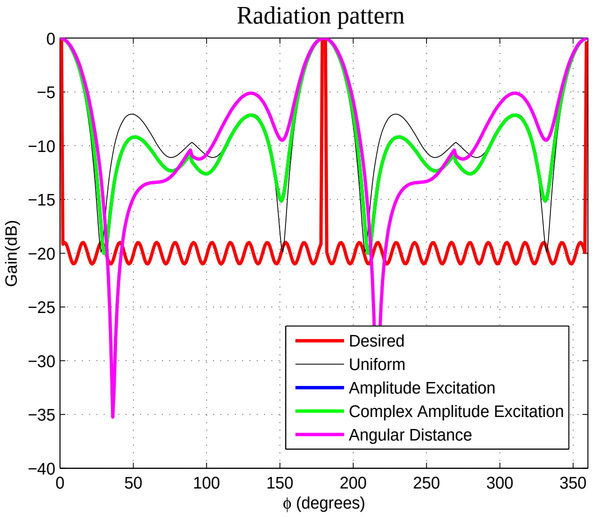
Figure 4.14: Polar plot of a CiAA for ang dist

4.4.4 Comparative and Statistical Results of CiAA

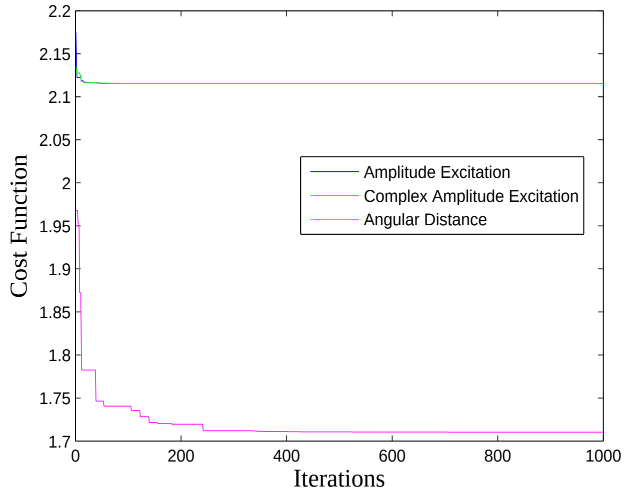
The statistical results of a circular antenna array with different excitations of amplitude, complex amplitude excitation and angular distance for the number of elements 10,20 and 30 using the MCS optimisation technique, calculated the the performance antenna parameters like directivity, HPBW and SLL and it values observed in the table 4.3. From the table angular distance giving better directivity with a value of 15.85 dB, HPBW with a value of 12^0 for the 30 elements compared to the complex amplitude and amplitude excitation and complex amplitude excitation giving better SLL of -19.5 dB compared to amplitude excitation and angular distance optimisation. By observing the statistical tables 4.3 and 4.2 the circualr antenna array giving better desired pattern synthesis compared to the linear antenna array4.15.

No. of Elements	Directivity (dB)			HPBW (DEGREE)			SIDE LOBE LEVEL (dB)		
	Amp	C-Amp	Ang Dist	Amp	C-Amp	Ang Dist	Amp	C-Amp	Ang Dist
10	11.6	11.75	11.98	30	29	29	-7.12	-7.08	-10.87
20	13.74	13.79	14.01	24	22	20	-19.94	-19.5	-18.39
30	15	15.51	15.85	16	14	12	-17.92	-18.58	-15.27

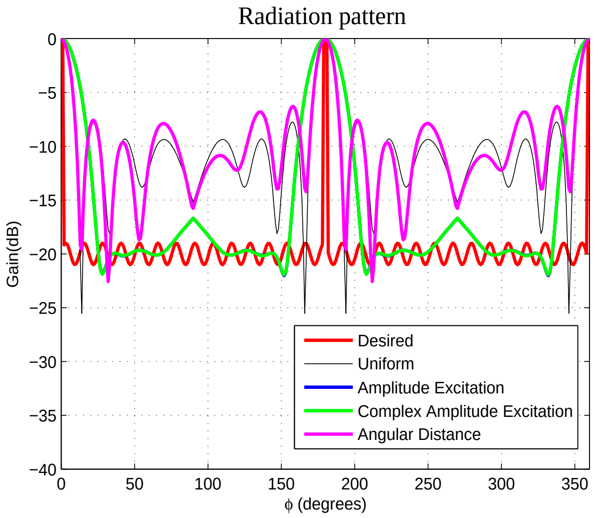
Table 4.3: Statistical results of a circular antenna array



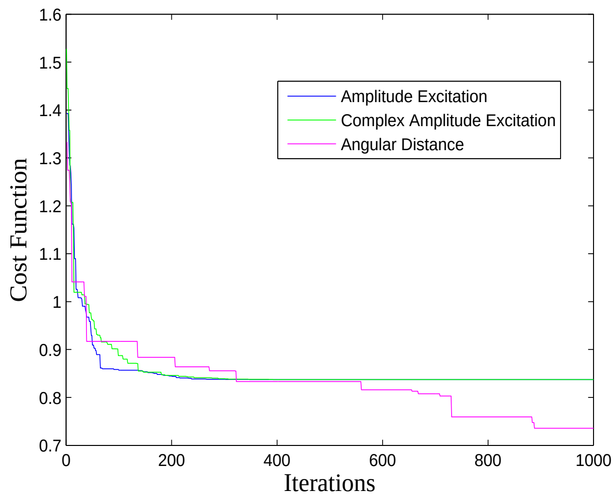
(a) rad pat of 10 elements



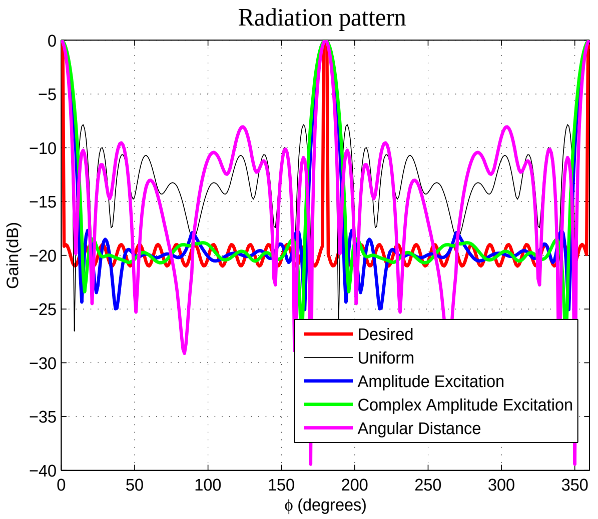
(b) cost fun of 10 elements



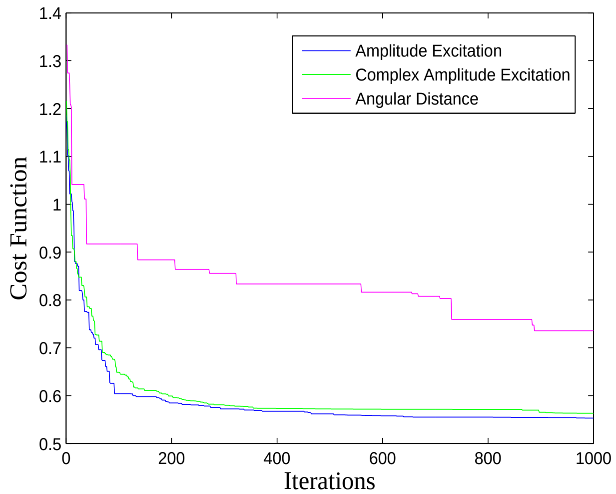
(c) rad pat of 20 elements



(d) cost fun of 20 elements



(e) rad pat of 30 elements



(f) cost fun of 30 elements

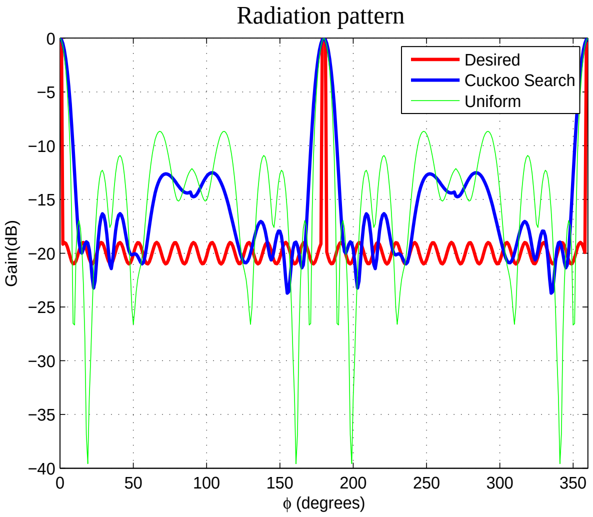
Figure 4.15: Combined plots of Rad and cost fun of a CiAA

4.5 Case study 3: Conical Antenna Array

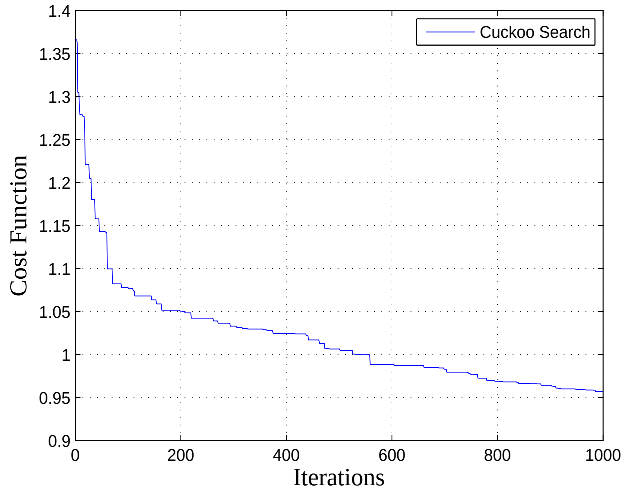
From the conical antenna array the parameters can be varied we can observed from the array factor eq^n 2.7, we can optimise the conical antenna array for desired pattern synthesis with excitations of amplitude, complex amplitude and angular distance optimisation using MCS algorithm. For comparing the results considering 2,5 and 7 circular stacks of conical antenna array with number of elements are 36,60 and 140 and as the base circle to the above circle the no of elements reduced to 4 as follows [5, 10, 20].

4.5.1 Amplitude Excitation of CAA

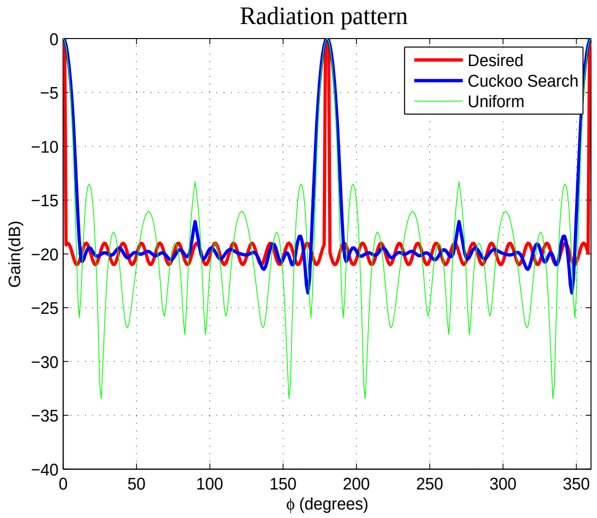
In amplitude excitation the amplitude(only magnitude) is varying and the below patterns are the radiation , cost function and polar plot for the CAA with amplitude excitation with the number of elements are 36,60 and 140. The Radiation pattern for N=36,60 and 140 elements using MCS for CAA with parameter changing amplitude excitation are shown in figure 4.16. From the figure 4.16, observing that 'a','c' and 'e' are the radiation patterns and as the number of elements are increasing it reaching to desired pattern with HPBW of 6.5^0 and maximum directivity is 17.92 dB for 140 elements and for 36 and 60 elements the HPBW of 9^0 and 8^0 and the directivity are 15.91 dB and 17.51 dB [17, 11]. The cost function for the amplitude excitation using MCS for 2,5 and 7 circular stacks is given in figure (2) of 'b','d' and 'f'. By observing the cost function results the cost function starts at 0.94 and reaches to the minimum value of fitness is 0.52 for 7 circular stacks and for 2 and 5 circular stacks the fitness values starting at 1.36 and 0.94 and reached to fitness values of 0.48 and 0.96 and using amplitude excitation the minimum SLL reaches to the -18.57 dB for 7 circular stacks. The polar plot of the amplitude excitations of the CAA is shown in the figure 4.17 for the number of elements 36,60 and 140 [21, 19]. N=140 elements providing more directivity ,HPBW compared to LAA and CiAA can be observe from the staistical results table 4.4,4.3and 4.2.



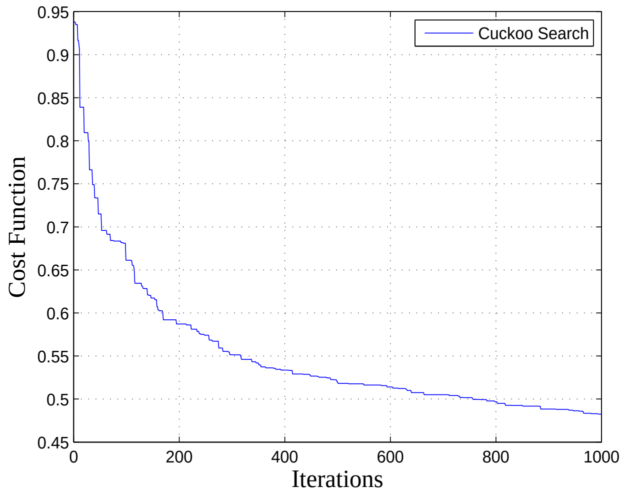
(a) rad of 36 elements



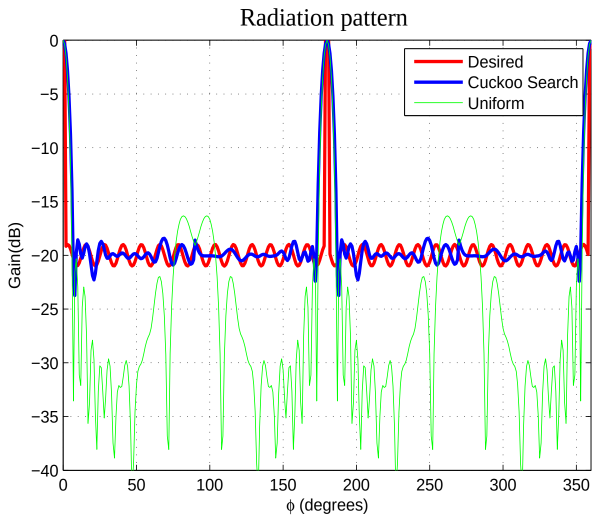
(b) cost fun of 36 elements



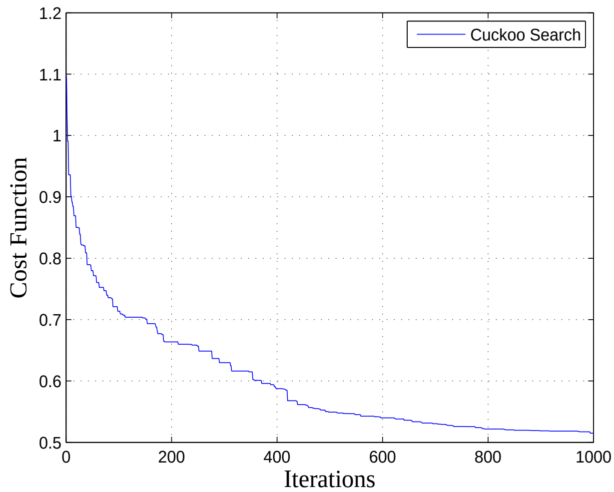
(c) rad of 60 elements



(d) cost fun of 60 elements

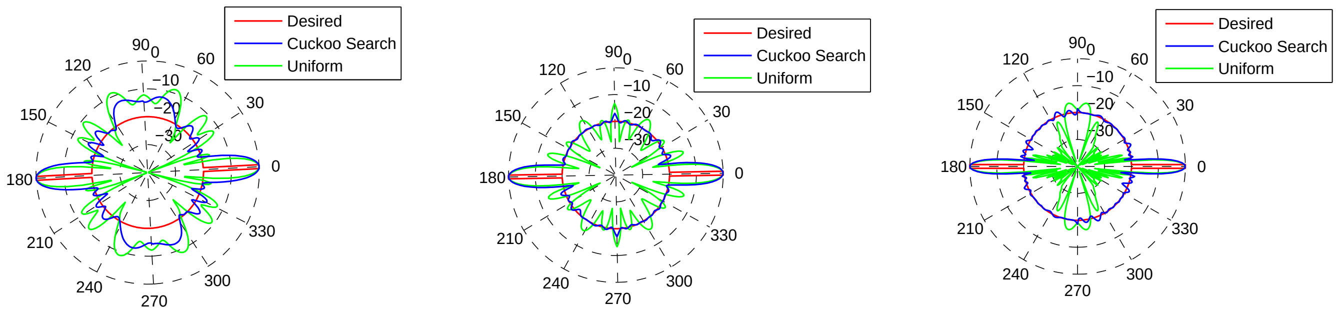


(e) rad of 140 elements



(f) cost fun of 140 elements

Figure 4.16: Rad and cost fun of a CAA for amp excit

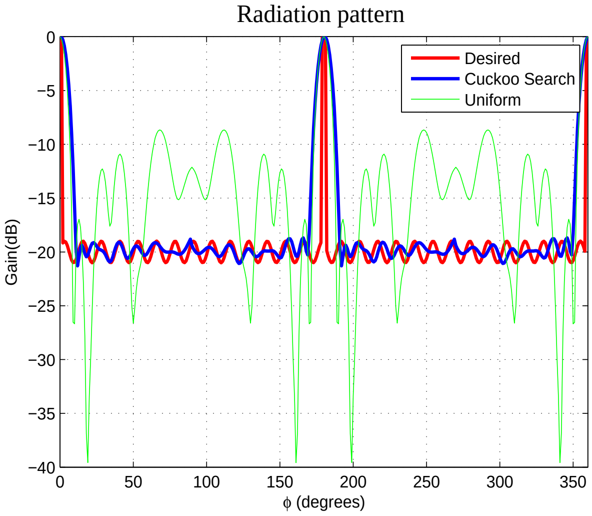


(a) n=36 elemnts (b) n=60 elements (c) n=140 elements

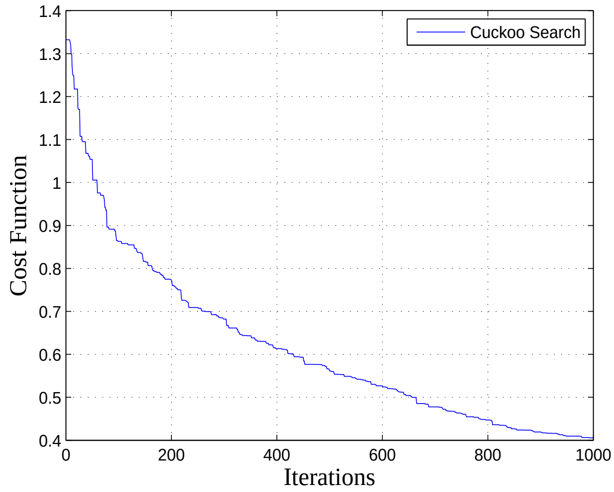
Figure 4.17: Polar plot of a CAA for amp excit

4.5.2 Complex Amplitude Excitation of CAA

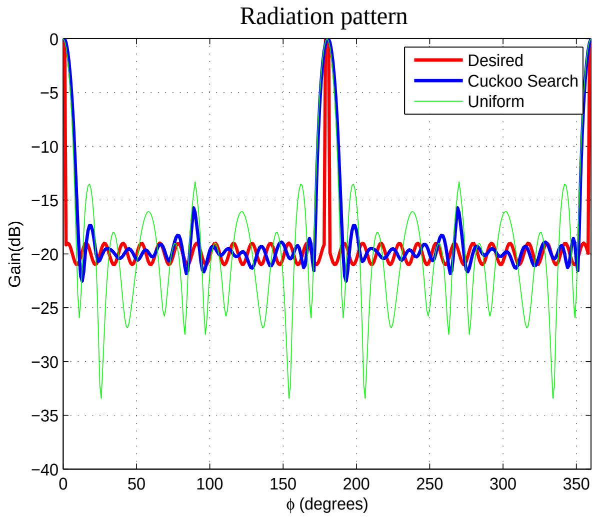
In complex amplitude excitation simultaneously the amplitude and phase of the the current varied hence optimizer will give better results than amplitude excitation. For the same no of circular stacks with complex amplitude excitation explained in figure 4.18. From the figure 4.18, 'a','c' and 'e' are represents the radiation pattern of the 36,60 and 140 elements and reaching the desired pattern with a HPBW of 6^0 and maximum directivity of 18.75 dB for 140 elements,for a and c the HPBW are 8^0 and 7.5^0, directivity are 16.41 dB and 17.8 dB. Hence observing these two,say that complex excitation giving better HPBW and directivity compared to amplitude excitation. from the figure 4.18 of 'b','d' and 'f', the cost function be analysed and for 140 elements the cost function starts at 1.1 and reaching to the minimum fitness values 0.46, and for remaining 2 and 5 circular stacks the cost function starts at 1.34 and 0.9 and reaching to fitness values of 0.4 and 0.45. By observing the figure 4.18 of (d) and (f),the complex excitation is more converges to the value of 0.46 and it is better than the amplitude excitation and it reaches to minimum SLL of -19.15 dB for 7 circular stacks [15, 22, 18]. The polar plot of the complex amplitude excitation of the circular antenna array is shown in the figure 4.19 for the number of elements 36,60 and 140 [29]. From the figure we are observing that as number of elements increasing it is reaching to the desired pattern we can clearly observe in the figure 4.19.



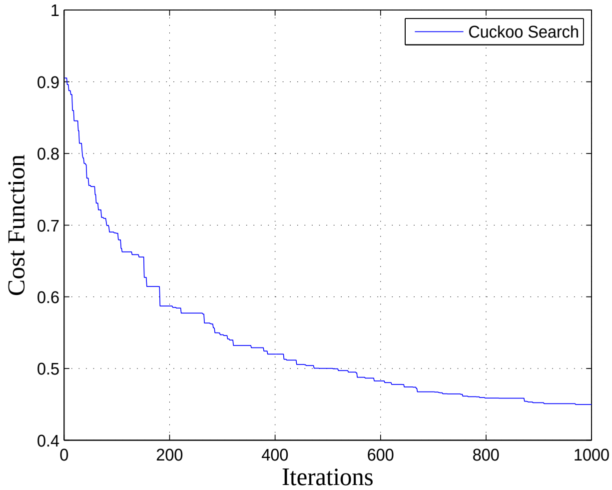
(a) rad of 36 elements



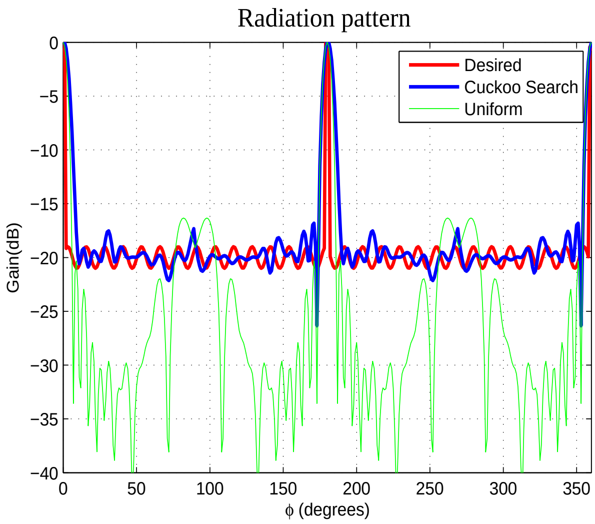
(b) cost fun of 36 elements



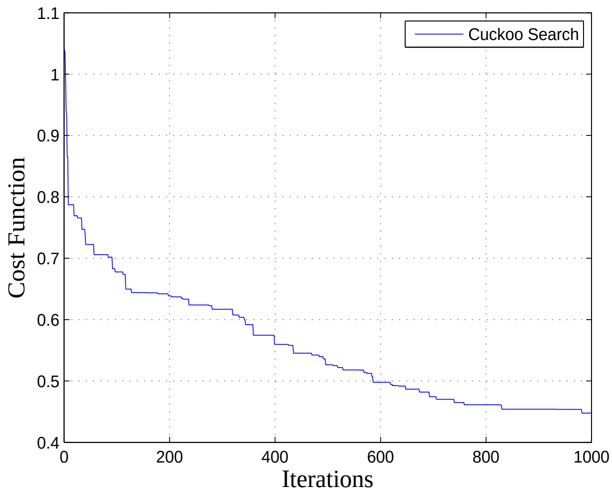
(c) rad of 60 elements



(d) cost fun of 60 elements

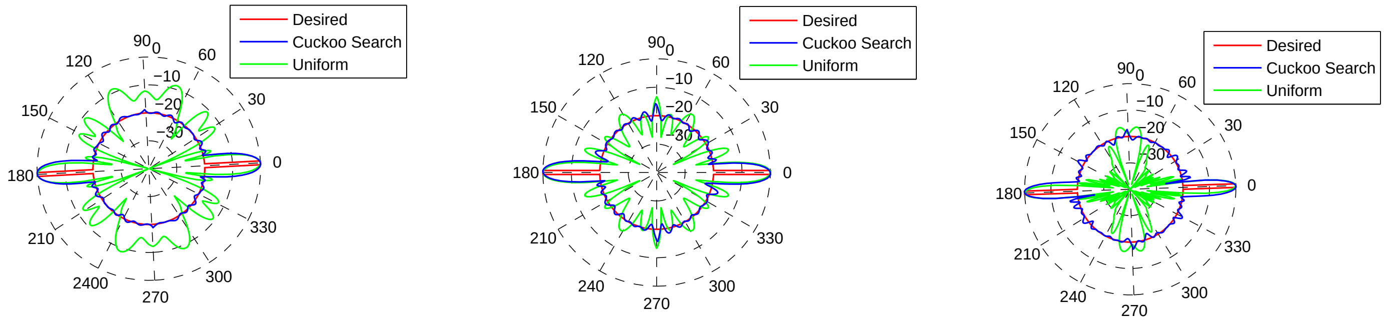


(e) rad of 140 elements



(f) cost fun of 140 elements

Figure 4.18: Rad and cost fun of a CAA for compx amp excit

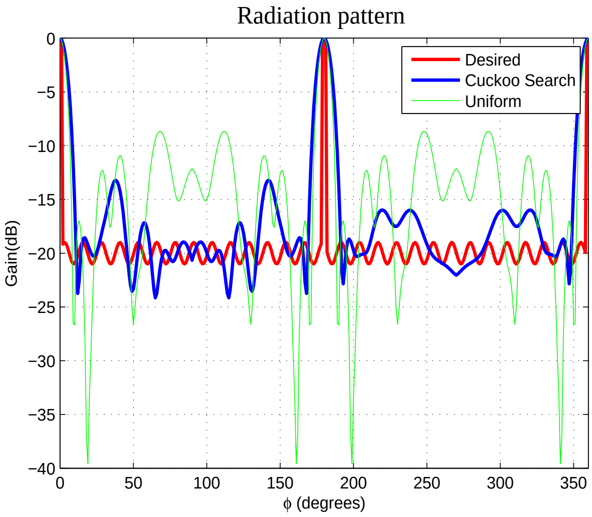


(a) n=36 elements (b) n=36 elements (c) n=36 elements

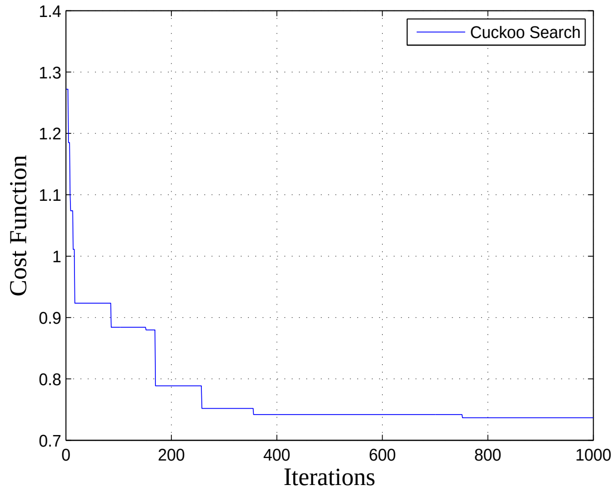
Figure 4.19: Polar plot of a CAA for compx amp excit

4.5.3 Angular Distance Optimisation of CAA

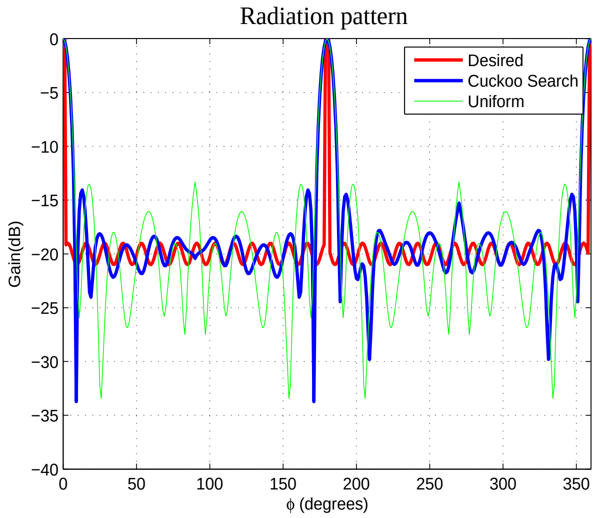
In angular distance optimization,the azimuthal phase(ϕ_n) of the circular stacks is varied for getting good directivity compared to amplitude and complex amplitude excitation. From the figure 4.20,'a','c' and 'e' represents the radiation patterns for the 2,5 and 7 circular stacks and it reaches the HPBW of 5.5^0 and maximum directivity of 19.3 dB for 7 circular stacks and the remaining 2 and 5 circular stacks the HPBW are 8^0 and 7^0, directivity reaches to 16.72 dB and 18.1 dB. By observing the figure 4.20,it has more SLL fluctuations compared to the complex amplitude and amplitude and it reaches to minimu SLL of -18.61 dB in 2 circular stacks because as number elements increases the fluctuations will be more. The cost function explained from the figure 4.20 of 'b','d' and 'f' and the minimum fitness values reached in 7 circular stacks started at 0.875 and reached to 0.68, for the 2 and 5 circular stacks the fitness vlues started at 1.28 and 0.89 and reached to 0.74 and 0.67 and in distance optimization. The polar plot of the complex amplitude excitation of the circular antenna array is shown in the figure 4.21 for the number of elements 36,60 and 140 [21]. From the figure observing that as number of elements increasing it is reaching to the desired pattern we can clearly observe in the figure 4.21. The angular distance optimisation providing better performance compared to the complex amplitude and amplitude excitations [13, 17, 5, 13].



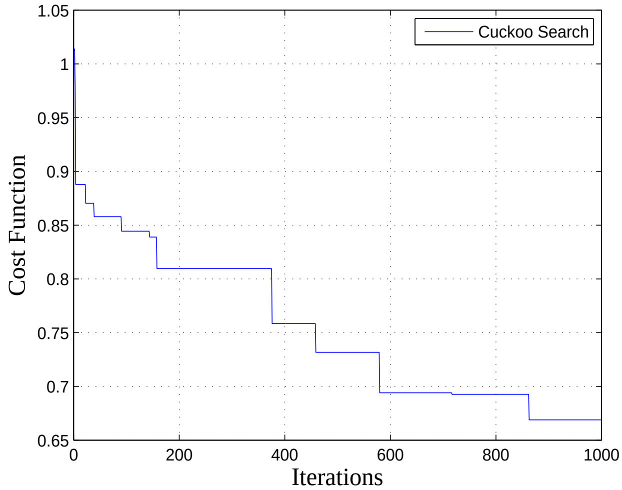
(a) rad pat of 36 elements



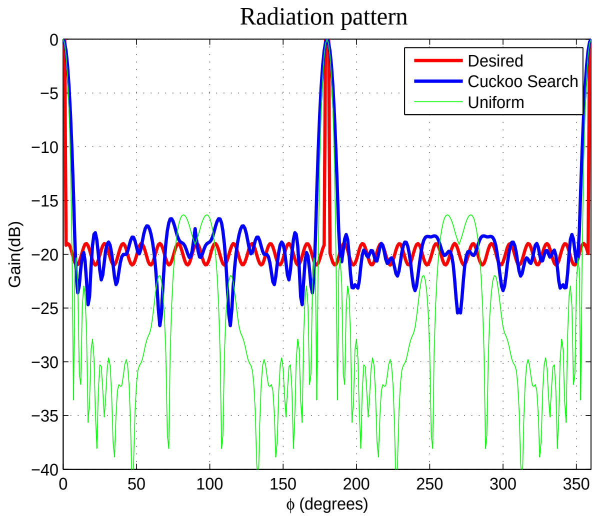
(b) cost fun of 36 elements



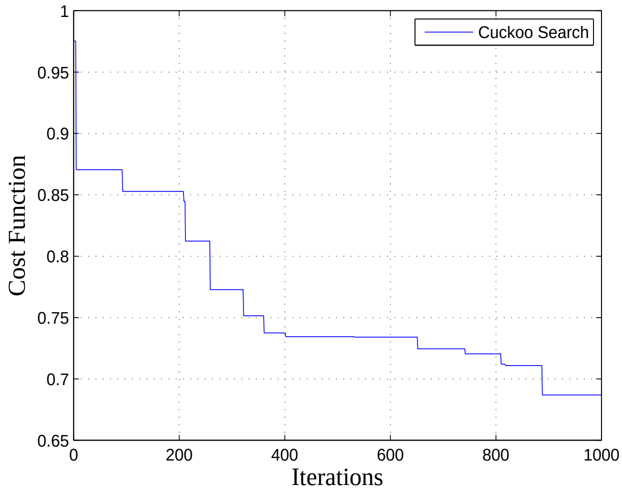
(c) rad pat of 60 elements



(d) cost fun of 60 elements

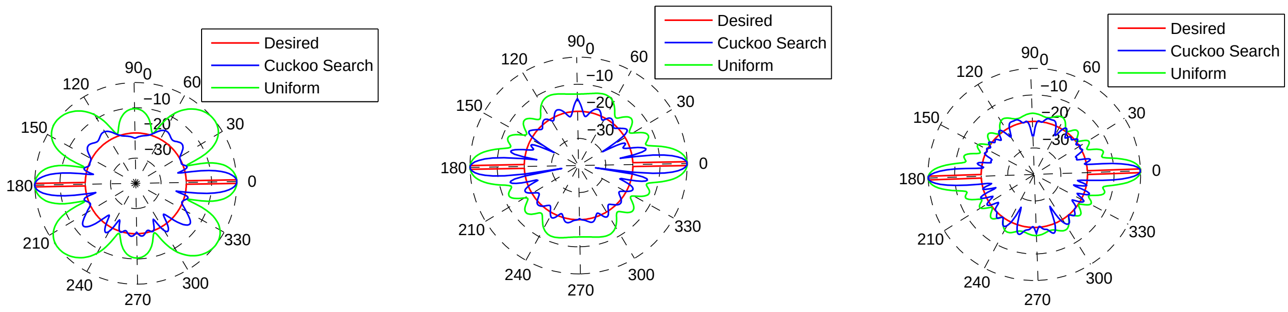


(e) rad pat of 140 elements



(f) cost fun of 140 elements

Figure 4.20: Rad and cost fun of a CAA for ang dist opt



(a) n=36 elements (b) n=60 elements (c) n=140 elements

Figure 4.21: Polar plot of a CAA for ang distance opt

4.5.4 Statistical Results of CAA

The statistical results providing the performance of the CAA by the antenna parameters are directivity,HPBW and side lobe level (SLL). The table 4.4 shows the statistical results of a 2,5 and 7 circular stacks of a CAA with the number of elements 36,60 and 140 elements. From the table 4.4, the angular distance optimization giving a maximum directivity of the value 19.3 dB and it is more than complex amplitude and amplitude excitations, the complex amplitude will give the the medium results and it reaches a maximum directivity of 18.75 dB and lower HPBW of 6 dB and it is better than amplitude excitation results. The side lobe level (SLL) are reached the minimum value of -19.15 in complex amplitude excitation and it is better than the amplitude excitation and angular distance. CAA providing better directivity, HPBW and SLL compared to the CiAA and LAA it can be proofed by the statistical tables of 4.4,4.3 and 4.2.

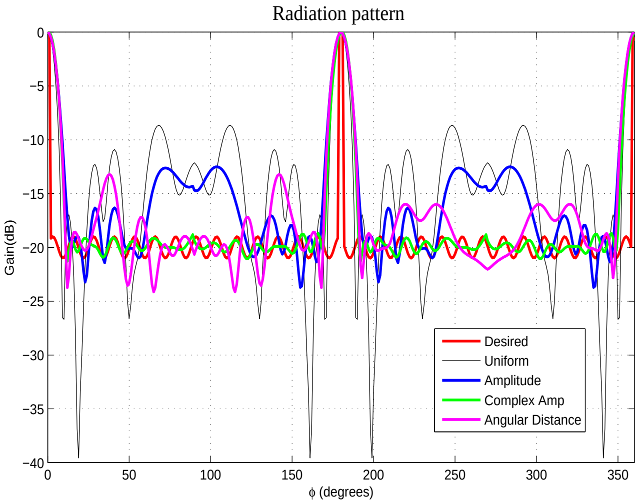
No. of Elements	Directivity (dB)			HPBW (DEGREE)			SIDE LOBE LEVEL (dB)		
	Amp	C-Amp	Ang Dist	Amp	C-Amp	Ang Dist	Amp	C-Amp	Ang Dist
36	15.9	16.41	16.718	9	8	8	-18.01	-18.7	-18.61
60	17.51	17.8	18.1	8	7.5	7	-18.36	-18.56	-15.5
140	17.92	18.75	19.3	6.5	6	5.5	-18.57	-19.15	-18.16

Table 4.4: Statistical results of a con ant array

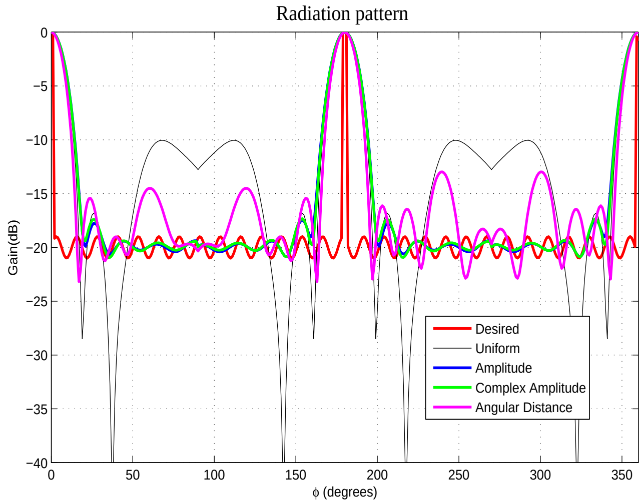
4.5.5 Comparative analysis of CAA with $\lambda/2$ and λ ang dist

In synthesis of CAA, in base circle the angular distance between the elements is taken as λ and $\lambda/2$ angular distance and from the results understanding that λ angular distance giving better results than $\lambda/2$ distance. In this figure 4.22, comparing the radiation patterns of a desired, uniform, amplitude, complex amplitude and angular distance optimization of a CAA on a single plot, where red represents desired pattern, black represents uniform excitation, blue represents amplitude excitation, green represents complex amplitude excitation and magenta represents angular distance optimization. Radiation pattern is a 2-dimensional plot, where x-axis represents the azimuthal angle [ϕ] and gain(dB) is on y-axis. The figure 4.22 represents the 2,5,7 circular stacks arrangement of a CAA with angular distance separation between elements with λ and $\lambda/2$. From the figure 4.22, observing that angular distance giving more fluctuations in SLL compared to the amplitude and complex amplitude excitations. In figure 4.22 of 'f', the CAA with $\lambda/2$ angular distance ,it reaches a maximum directivity of 16.50 dB and HPBW of 10^0 for 7 circular stacks with 140 elements and side lobe level reached a minimum value of -18.78 dB for complex amplitude excitation [5] and SLL reached to a level of -17.85 dB by amplitude and -15.43 dB with angular distance.

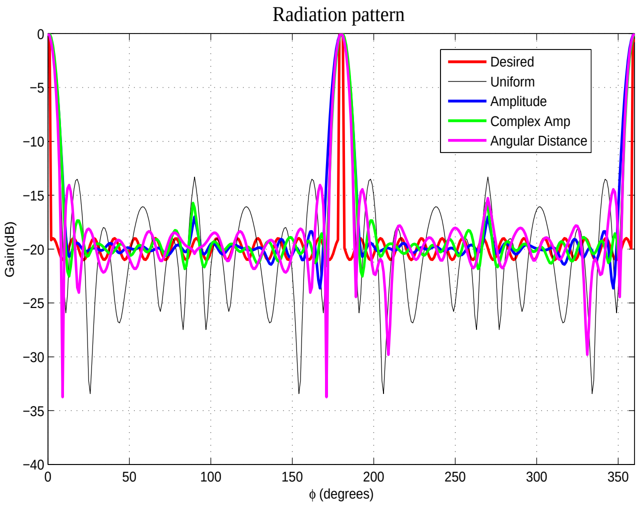
The figure 4.22 represents the combined radiation pattern for a 2,5 and 7 circular stacks with 36,60 and 140 elements with CAA with λ. [17, 21, 20].In figure 4.22 of 'e' represents the combined radiation pattern for a 7 circular stacks with 140 elements, observing the radiation pattern the SLL are good for complex excitation and it reaches a minimum value of -19.15 dB and the directivity is better in angular distance spacing compared to remaining that value is 19.3 dB and HPBW reaches a value of 5.5^0 with angular distance spacing. These statistical results can be viewed in table 4.4 as follows [11, 22, 27].



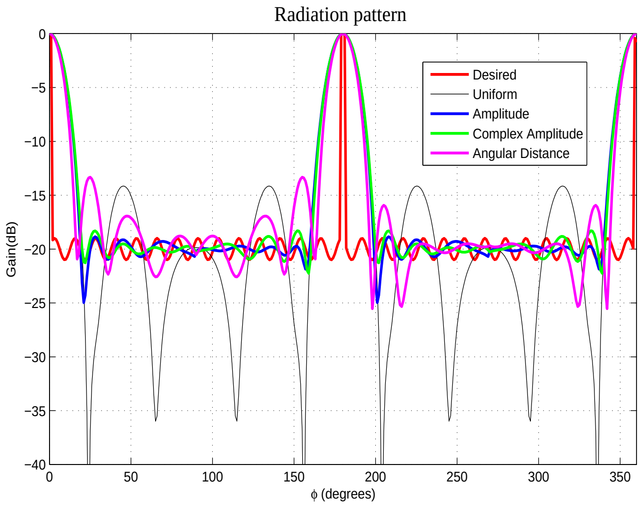
(a) n=36 elemens for λ distance



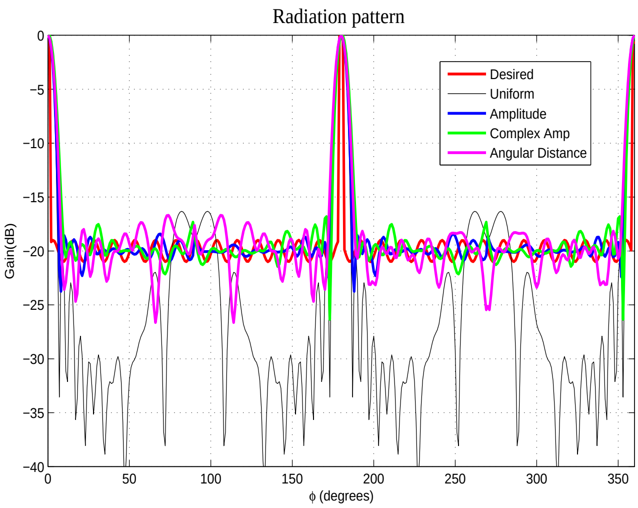
(b) n=36 elemens for $\lambda/2$ distance



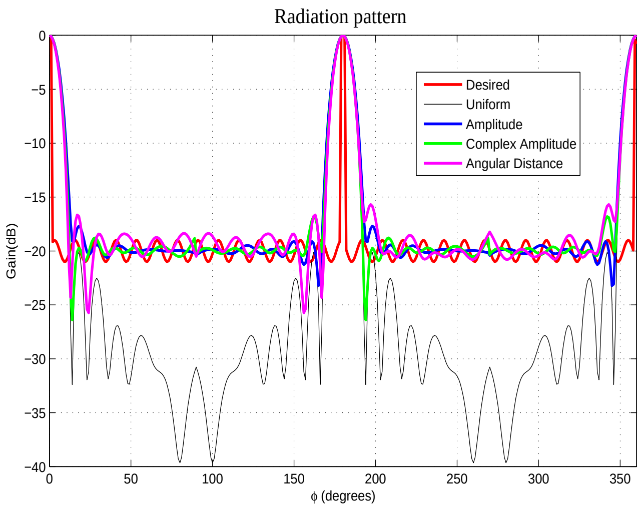
(c) n=60 elemens for λ distance



(d) n=60 elemens for $\lambda/2$ distance



(e) n=140 elemens for λ distance



(f) n=140 elemens for $\lambda/2$ distance

Figure 4.22: Rad pat of a CAA for $\lambda/2$ and λ ang dist

4.6 Validation of the MCS Algorithm

In this section we compare MCS and PSO(Khodier) keeping same constraints for same Linear Antenna Array. Linear antenna array is placed along x-axis which is symmetric w.r.t origin. The objective function is used [12, 10, 22] i.e.

$$\textbf{fitness} = min(max\{20log|AF(\phi)|\}) \tag{4.2}$$

subject to $\phi\varepsilon\{\ [0^0 76^0]$ and $[104^0 180^0]\ \}$

Simulation of linear antenna having a $2N = 16$ element having $\beta = 0$ and

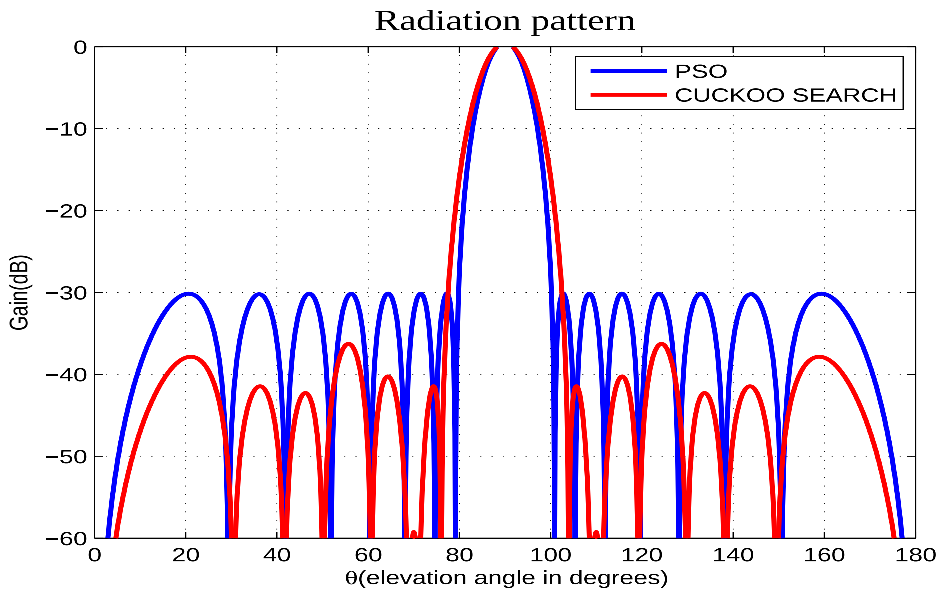


Figure 4.23: Radiation pattern of $2N = 16$ elements

Elements	Excitation	SLL(dB)
$\mid I_n \mid$(Khodier)	1.0000, 0.9521, 0.8605, 0.7372,	-30.7
	0.5940, 0.4465, 0.3079, 0.2724	
$\mid I_n \mid$(MCS)	1.0000 0.9268 0.8076 0.6575	-36.38
	0.4619 0.2992 0.1700 0.1028	

Table 4.5: Statistical results of pso and mcs

distance between two adjacent element is $\lambda/2$ and table 4.5 shows that MCS is better performing compared to PSO(Khodier) in constraint of maximum SLL. The maximum SLL of proposed optimization algorithm is -36.38 dB which is 5.65dB lower than PSO SLL(Khodier) observed from the table 4.5

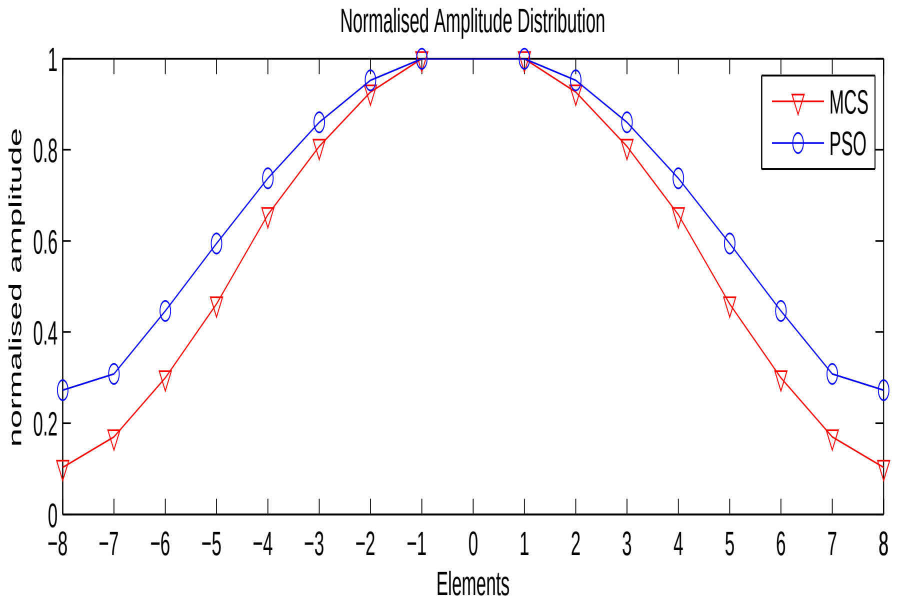


Figure 4.24: Normalized amplitude distribution of $2N = 16$ elements

[22]. Figure 4.24 show that normalized amplitude excitation obtain from MCS is less compare to PSO (Khodier) i.e. MCS performing better than pso therefore the validation of MCS is verified.

4.7 Matlab Results of a CAA results with GUI

GUI is a graghical user interface for changing the control parameters and giving the results simultaneously for the CAA in the matlab 12a software. The results of a CAA with 2 circular stacks with the number of elements 10,6 is showed in the figure 4.25. In this GUI of CAA the N_0, N_1, iter and runs are the input parameters and Pa, L are the controlling factors of the MCS algorithm for the CAA for providing the best results, and directivity, HPBW and SLL are the optimised values for howmuch it is reached the desired pattern.

- N_0, N_1 = The number of elements in the conical antenna array

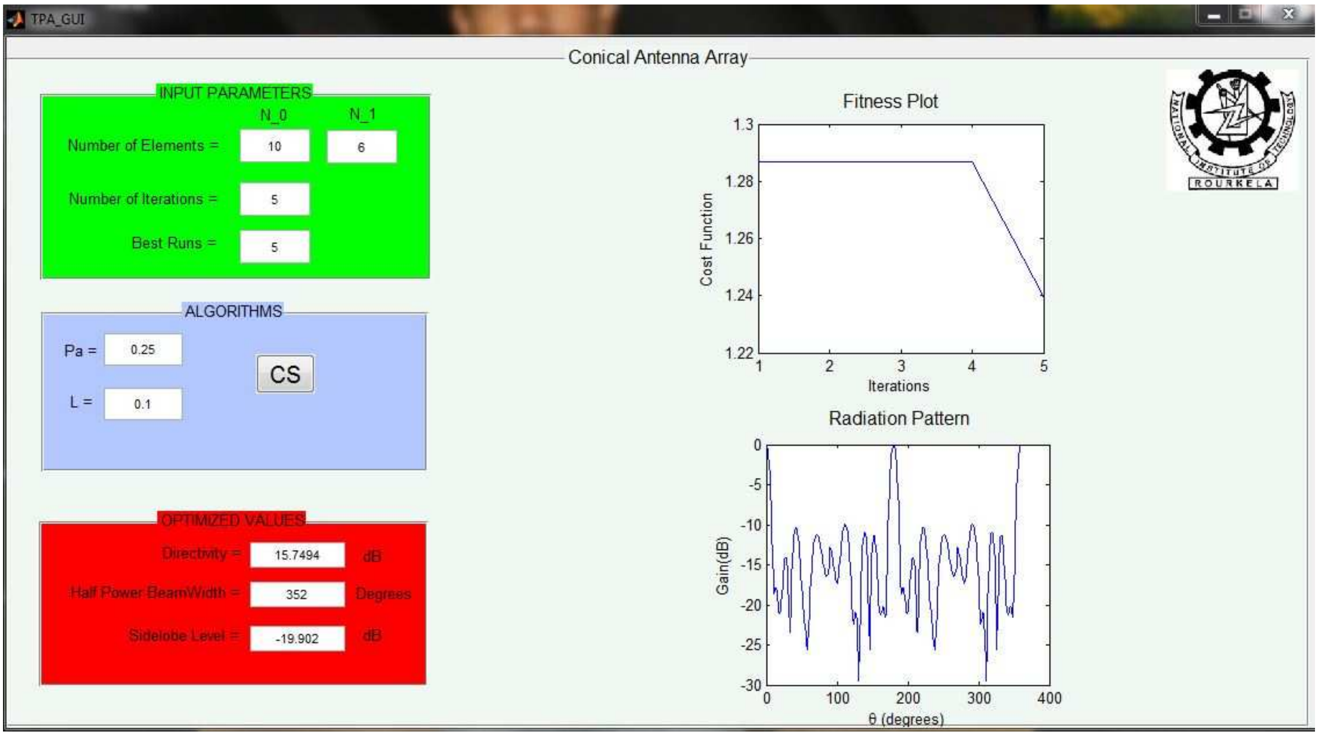


Figure 4.25: Matlab results of a CAA with GUI

- iter = Maximum number of iterations has to run
- runs = Maximum number of best runs with the iter
- Pa = Discovery rate of the alien egg/solutions
- L = Levy flight step size to the next iteration
- GUI = Graphic User Interface

4.8 Application Note

4.8.1 Covering of the two areas

In this section providing the applications of the pencil beam desired pattern synthesis by the conical antenna array are 180^0 coverage, satellite communications, submarine applications, point to point communications ,..etc. The desired pencil beam pattern having a main beam level with a HPBW of 4^0 at (0^0,180^0). For example we have to cover 2 areas (cities) in between either forest or any river etc are there, we have to send the radiation to these areas excepting the forest or river is possible with the conical antenna array with the pencil beam desired pattern with accurate because changed the radiation to only two possible angels in opposite directions i.e 0^0 and 180^0 therefore losing of the radiation in other directions will be less hence the radiation in the desired direction is more i.e strong signal will be delivered therefore it is identify the signals or communications is very easy, and its geometrical view can be observed from the figure 4.26 and the image in the diagram is taken from the reference internet google search. In the diagram the desired pattern polar plot is also showed it is radiating towards 0^0,180^0 and at the remaining areas it radiates very less (neglected) it is possible with the conical antenna array as follows [5, 20].

4.8.2 Submarine Applications

In this section providing the submarine application with the pencil beam desired pattern synthesis by the conical antenna array. The submarine is in a very deep low under the sea comes under the navy to protect from the other countries to attack through the sea, therfore the submarine is always under the sea. The submarine entrance is designed like conical type because it can penetrate very easily and with high speed within the water and we are designed a desired pattern covering a region of 0^0,180^0 and the conical antenna array will provide the desired one with very accurate. By the submarine with this desired pattern we can detect the object of other countries where ever

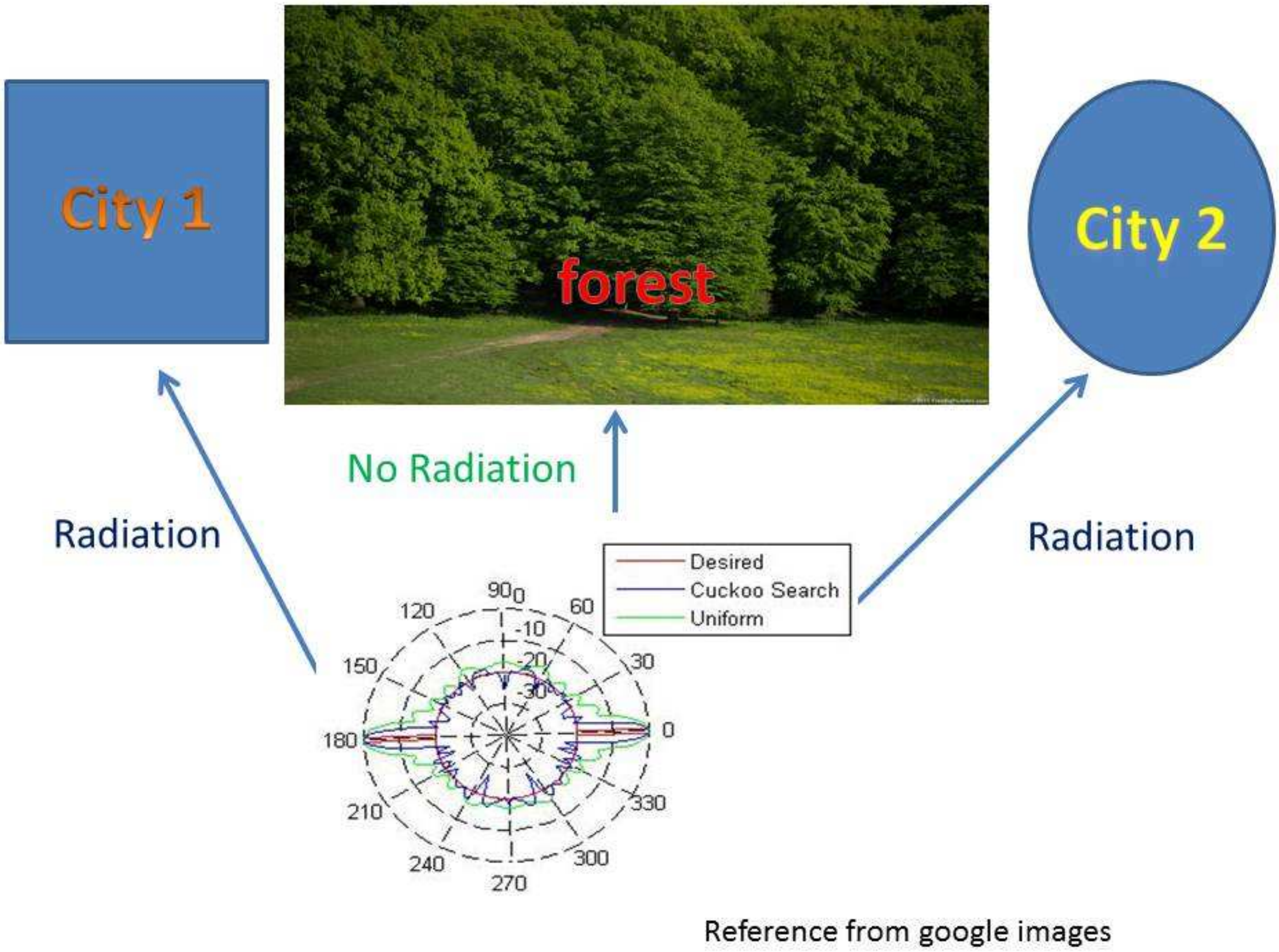


Figure 4.26: Covering of the two areas with desired pattern

it moves within the coverage of 0^0,180^0 very easily, therefore we can protect strongly through navy i.e. through the sea [5, 20]. The geometrical view of the submarine application is shown in the figure 4.27 and the diagrams of submarine and defence aeroplanes are taken from the reference internet google search for explaining purpose.

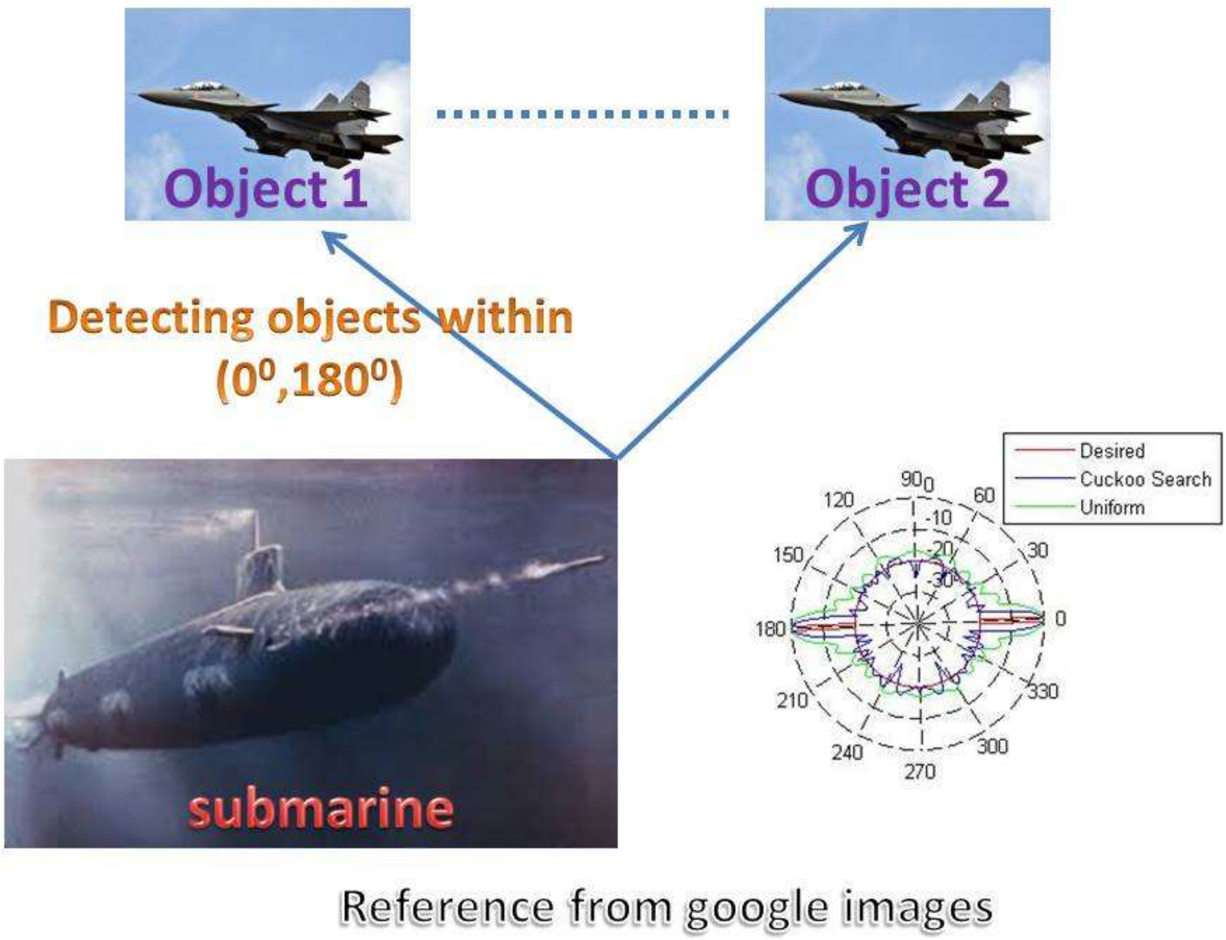


Figure 4.27: Submarine applications

Chapter 5

CST Results

5.1 CST Results for Conical Antenna Array

The cst is a computer simulation technology to offer wide range of EM simulation software to design EM spectrum, from static and low frequency to microwave and RF, including EDA and electronics, EMC and EMI and charged particle dynamics. The cst studio suite comprises of complete set of 3-D electromagnetic simulation tools, along with a number of related products dedicated to more specific design areas such as cable harnesses, PCBs and EM/circuit co-simulation,etc. For designing of the antenna array synthesis for the desired patterns using cst tools with education licence only.

The designing of the conical antenna array with the antenna elements as printed dipole antenna for practical(hardware) design in the CST studio suite for the 2 and 4 circular stacks with the number of elements 2x4 and 4x4 elements and the corresponding designs, radiation pattern of 2-D plot, 3-D plot and polar plot of the both the printed dipole antenna and CAA synthesis in the CST studio suite is shown in figures. For designing of the conical antenna array synthesis, the patch dipole antenna is used as a radiating element hence the detailed description of the dipole antenna and its simulation in the CST will be as follows.

5.2 Patch Dipole Antenna

A patch dipole antenna is a low profile antenna and it has so many advantages like lightweight, inexpensive, and easy to integrate with accompanying electronics compared to other type of antennas. Micro strip antennas consisting very thin metallic strip (t << λ_0, where λ_0 is free space wave length) and its wavelength (h << λ_0) above a ground plane. The micro strip is chosen because it will provide maximum pattern compared to other antennas [2]. For a rectangular patch, the length of the element is ($\lambda_0/3 <$ L $< \lambda_0/2$) and dielectric constant are in the ranges of ($2.2 \leqslant I_r \leqslant 0.05\ \lambda_0$) and these are providing desirable antenna performance with thick substrates and lower dielectric constant are providing better efficiency, larger bandwidth with large element size, therefore we are going to thin substrate with high dielectric constant are using in microwave circuits for minimizing radiation and coupling with smaller element sizes [24, 25, 26]. The geometric view of the patch dipole antenna is as shown in the figure 5.1. The width and height of the patch dipole antenna and the radius of the circle in the patch dipole antenna is 0.375cm

width of the patch dipole antenna = 2*L_1+g_1

height of the patch dipole antenna = W_1+L_4+L_3+L_6

The mathematical equations and calculations of the patch for designing at the frequency 2.4 GHz we have to know the width (W), height (h), permeability(ε_r), effective length (L_e), effective dielectric constant (ε_{reff}), extended incremented length of patch (ΔL) and resonant frequency (f_r) of the patch. The necessary equations used to find width (W) and height(h) of the patch dipole antenna for theoretical way and correspondingly we will also design the patch dipole antenna in cst with these parameters [23, 2, 4].

$$W/h > 1 \tag{5.1}$$

$$W = \frac{1}{2f_r\sqrt{\mu_0\epsilon_0}} * \sqrt{\frac{2}{\varepsilon_r + 1}} \tag{5.2}$$

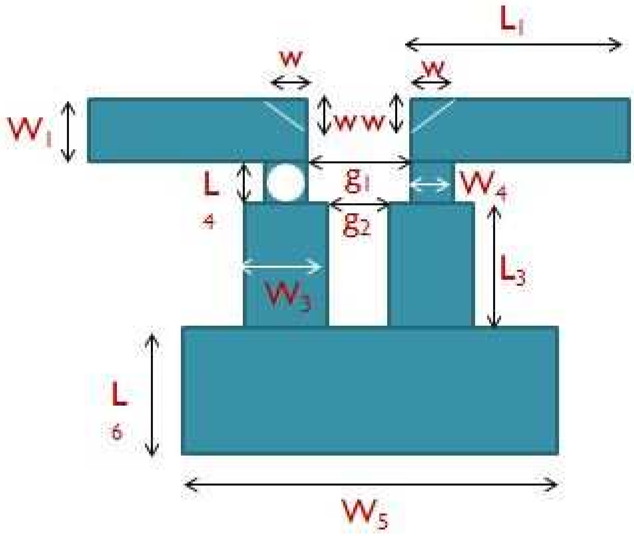


Figure 5.1: Geometric view of patch dipole antenna

$$\varepsilon_{erff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}[1 + 12\frac{h}{W}]^{\frac{-1}{2}} \tag{5.3}$$

$$\Delta L = \frac{0.412(\varepsilon_{erff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{erff} - 0.258)(\frac{W}{h} + 0.8)} \tag{5.4}$$

$$L = \frac{\lambda}{2} - 2\delta L \tag{5.5}$$

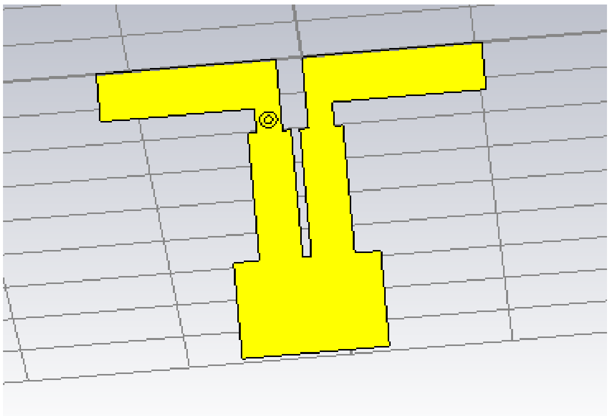
$$\lambda = \frac{1}{f_r \sqrt[1]{\varepsilon_{erff}\mu_0\epsilon_0}} \tag{5.6}$$

$$L_e = L + 2\delta L \tag{5.7}$$

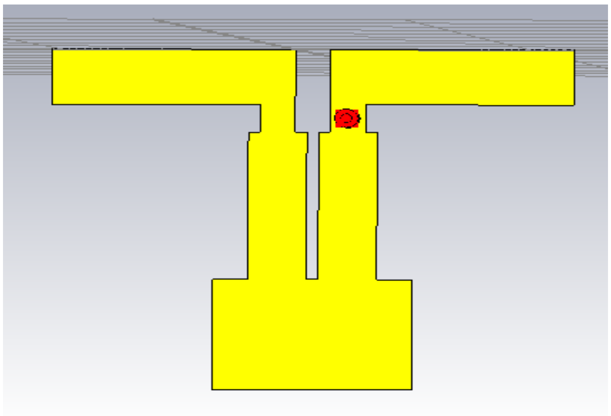
The Table 5.1 represents the patch dipole antenna measurements to design the patch antenna in cst tool software for designing the conical antenna array synthesis [24]. The patch dipole antenna are designed in cst studio suite with materials teflon-4, and the geometric view of the front view and back view of the patch dipole antenna with the patch measurements from the table 5.1 is shown in the figure 5.2. The 3-D plot of the patch dipole antenna and it polar plot at the frequency 2.4 GHz are shown in the figure 5.3 and 5.4. The patch antenna design from the consideration that the observer is at far field, and the directivity obtained when uniform excitation is feed to the patch dipole antenna is 3.31 dB and side lobe levels is -2.4 dB.

Parameter	Value in mm
Dipole strip	$L_1 = 20.8$ $W_1 = 6$ $g_1 = 3$ $L_2 = 32$ $L_3 = 16$ $L_4 = 3$ $L_5 = 3$
Microstrip Balun	$W_2 = 2$ $W_3 = 5$ $W_4 = 3$ $g_2 = 1$
Via radius	$r = 0.375$
Ground plane	$L_6 = 12$ $W_5 = 17$
Side of micro-strip bend	l variable (0− 3)
Side of dipole's arms in the gap	w variable (0 − 3)

Table 5.1: Patch dipole antenna measurements



(a) Patch front view



(b) Patch back view

Figure 5.2: Patch front and back view

5.3 CST Results of a Conical Antenna Array

Conical antenna array was designed with 2x4, 4x4 circular stacks with the number of elements are 8, 12 using cst and getting the required desired pattern with increasing the number of elements but we are using the cst educational license software hence it is not possible to get for the number of elements hence showing for the antenna elements 8, 12(2x4 and 4x4) and each circle having 4 number of elements [5, 20]. Here showing the geometric view,

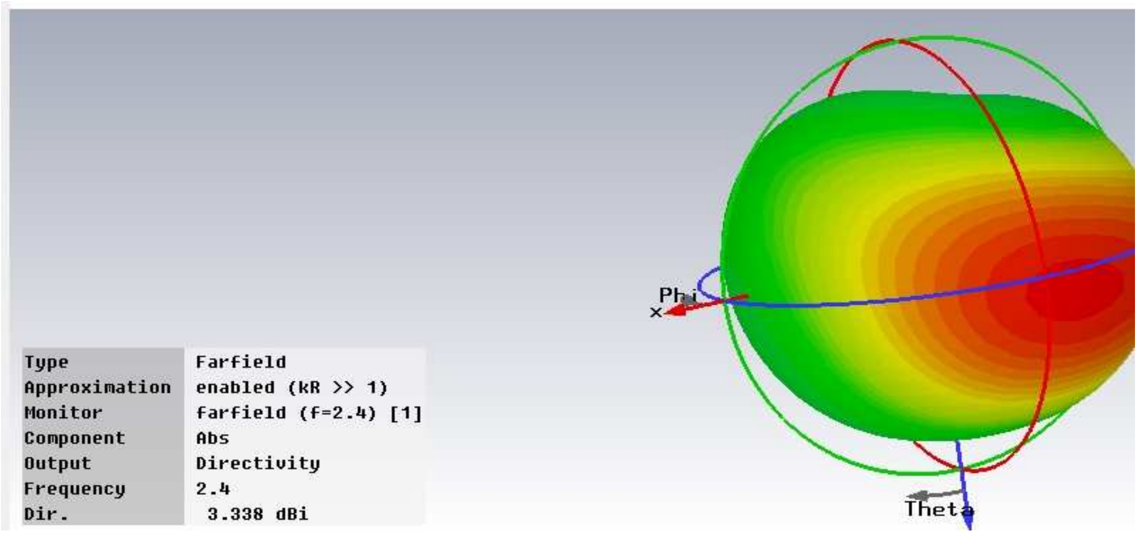


Figure 5.3: 3D plot of patch dipole antenna

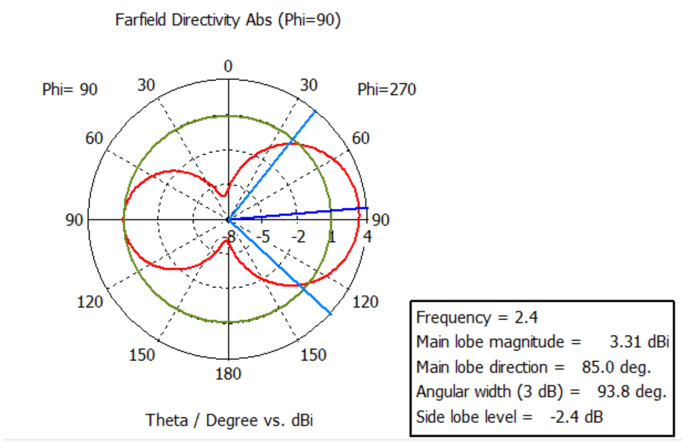
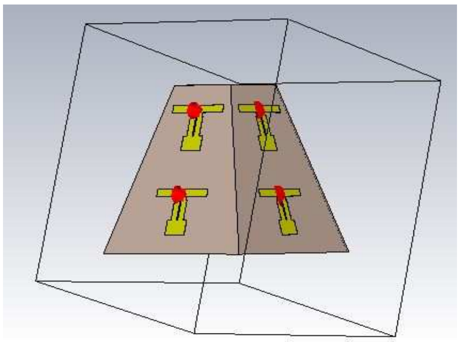
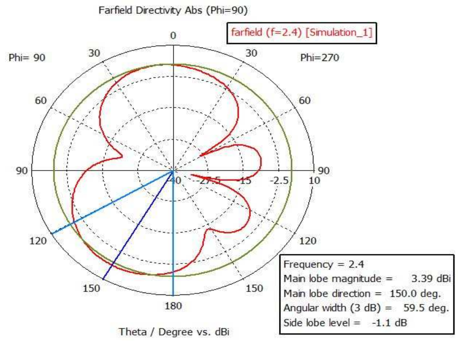


Figure 5.4: polar plot of patch dipole antenna

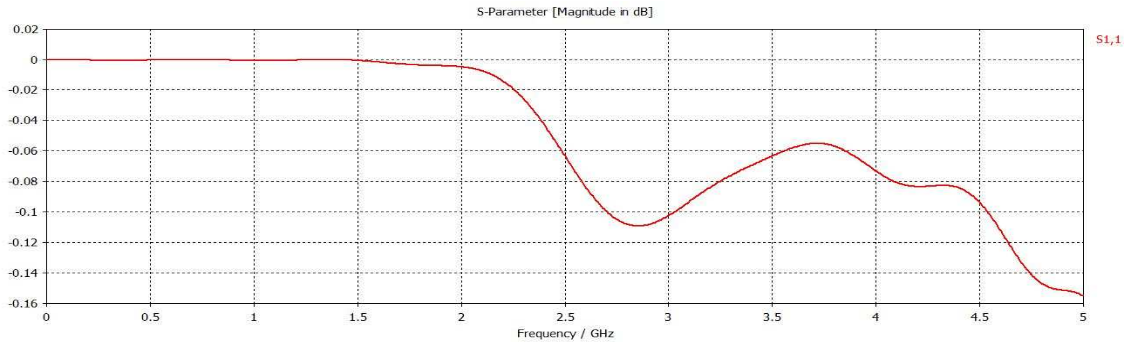
polar plot, s11, 3-D plot and cartesian plot of the circular stacks of 2x4 and 4x4 at frequency 2.4 GHz and corresponding diagram showed in the figures 5.5 and 5.6.



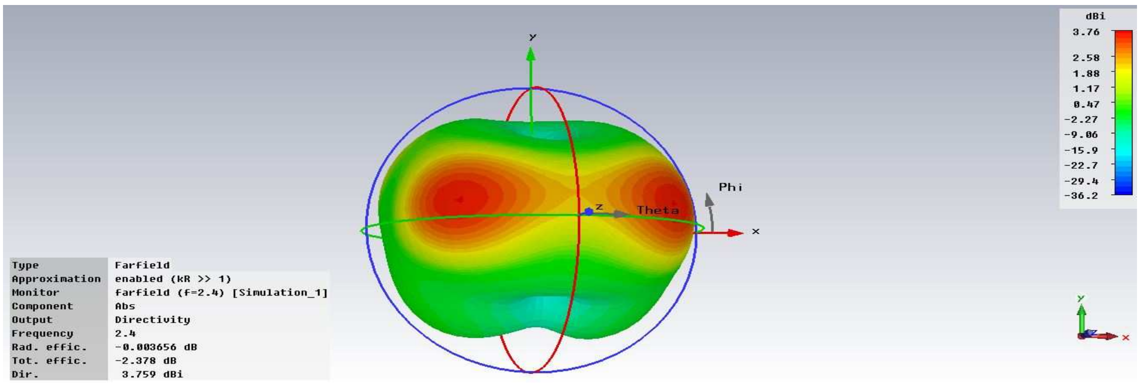
(a) Geometric view



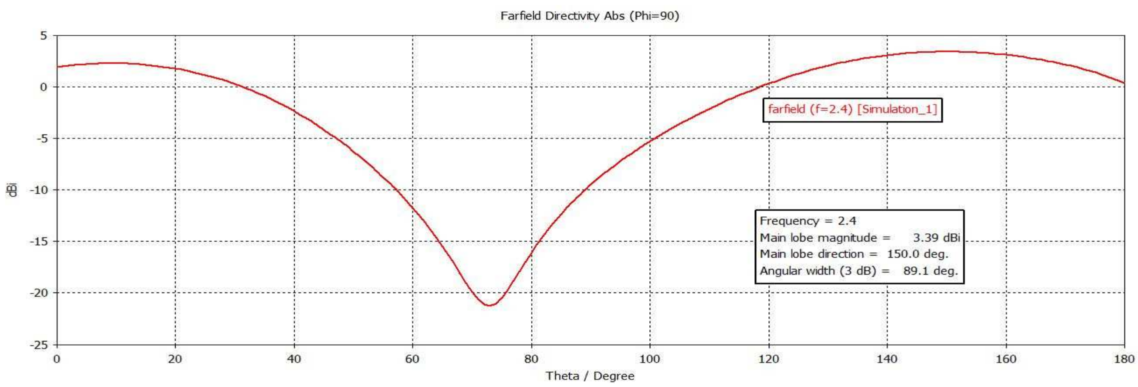
(b) Polar plot



(c) S11 of the 2x4 conical ant array

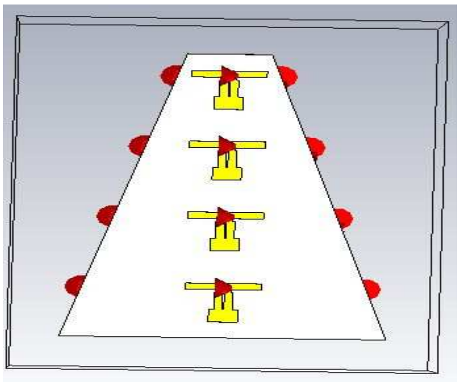


(d) 3D plot of the 2x4 conic ant array

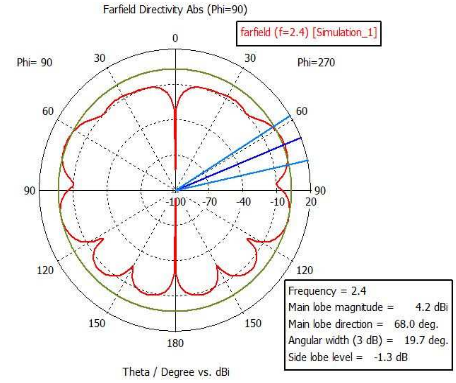


(e) Cartesian plot

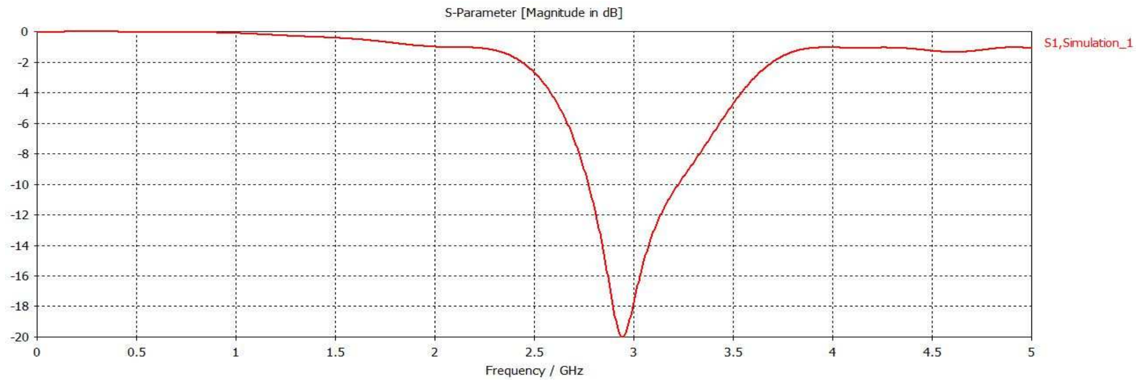
Figure 5.5: CAA synthesis using cst for 2x4



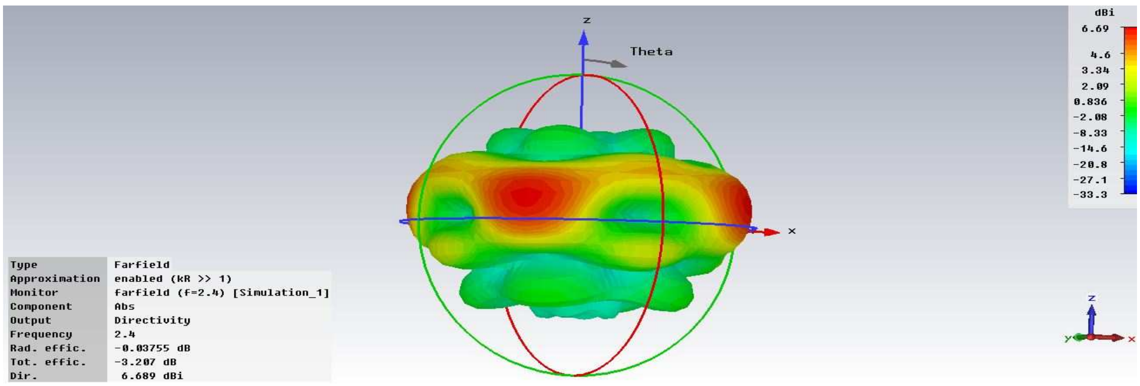
(a) Geometric view



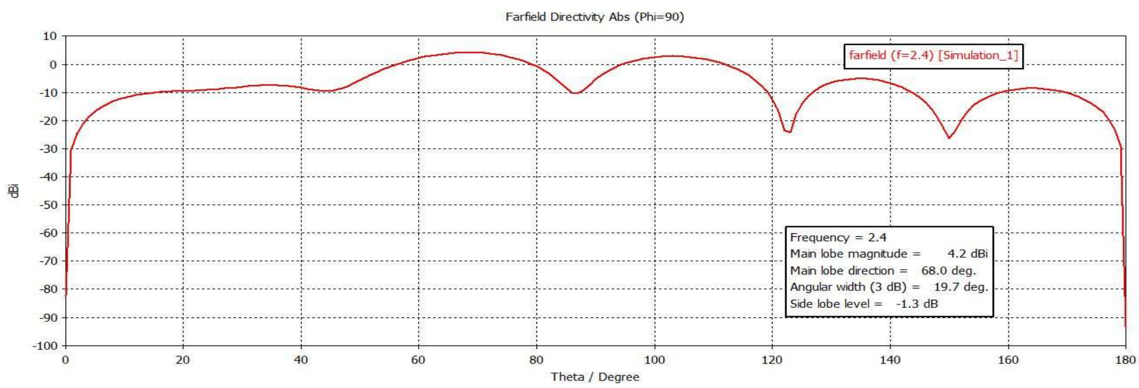
(b) Polar plot



(c) S11 plot

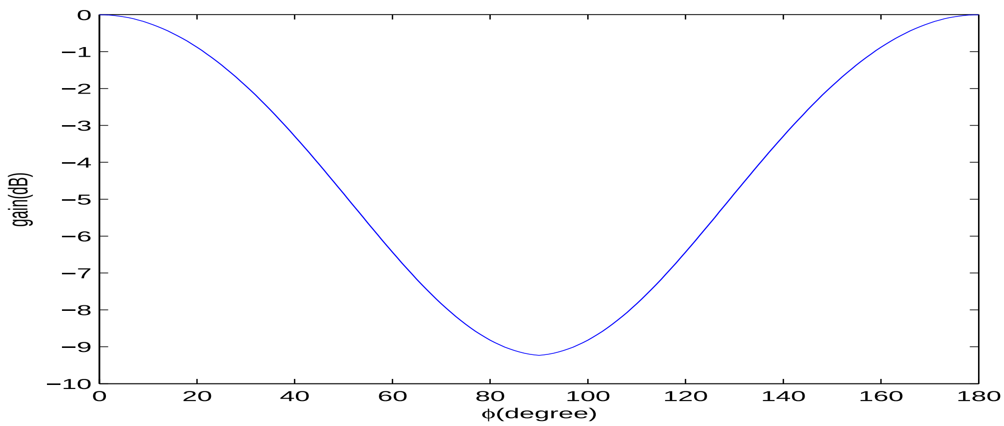


(d) 3D plot of the conic ant array

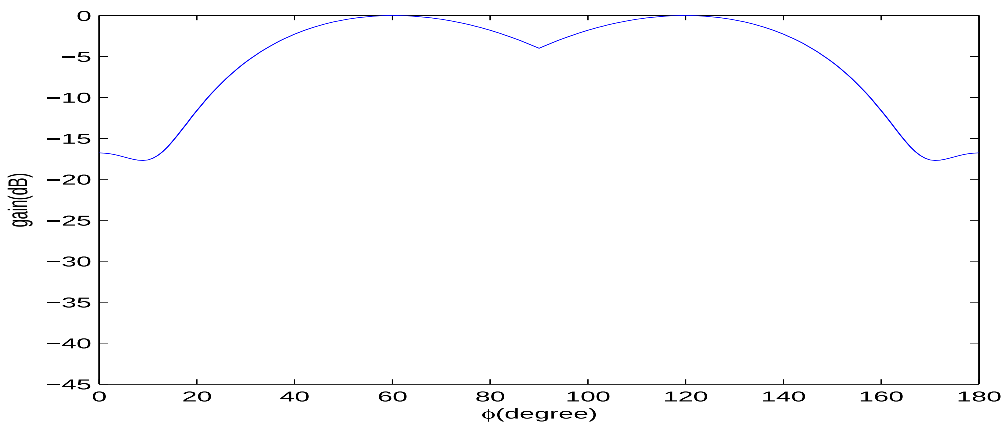


(e) Cartesian plot

Figure 5.6: CAA synthesis using cst for 4x4



(a) 2x4 patch in matlab



(b) 4x4 patch in matlab

Figure 5.7: Total radiation patten of CAA using matlab

5.3.1 Comparasion of cst and matlab for conical ant array

Total radiation pattern of conical antenna array design and synthesis using patch dipole antenna as a antenna element and the results of the conical antenna array for 2x4 and 4x4 are showed in the figure 5.7. Here we are comparing the results of the conical antenna array with cst and conical antenna with matlab using patch antenna as a element with number of circular stacks 2,4 and elements are 8, 12(2x4 and 4x4) and we are getting the approximate results in both cst and matlab we can observe from the figures 5.7, 5.5 and 5.6.

Chapter 6

Conclusion and Future Scope

6.1 Conclusion

- Conical antenna array can be utilized for beam scanning, more coverage,..etc.
- Conventional arrays are fails for the production of the pencil beam desired pattern synthesis.
- The pencil beam explores more application in the area of satellite communications, submarine applications,..etc.
- The performance of the CAA is better than both LAA and CiAA by observing the simulation results and statistical tables.
- An attempt is made to change the antenna arrays optimisation with changing the parameter progressive phase shift(β).
- The virtual prototype CST model adds on to the verification of the simulation results.
- The CAA is modelled using CST studio suite with patch dipole as radiating element.

6.2 Limitations and Future Scope

6.3 Limitations

- Through out the work the mutual coupling between the antenna array elements is neglected.
- Identical antenna elements are considered.
- Applicable to the far field observations only.
- If cone angle is small it covers only the 180^0 coverage.

6.4 Future Scope

- Other algorithms nature and bio inspire can also be explored.
- All the controlling parameters can be utilized in the same model.
- Neuro-Fuzzy tecnique can also be experimental work can be expanded.
- Near field analysis can be extended.

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